ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

PROJECT NO. 2 - OPERATIONS AT HIGH TEMPERATURES

Report On

Sub-Project No. 2-11, Influence of High Temperatures upon the Efficiency of Personnel

Sub-Project No. 2-13, Effect of Training upon the Efficiency of Performance at High Temperatures

Sub-Project No. 2-17, Study of the Physiologic Effects of High Temperatures

SUBJECT: THE UPPER LIMITS OF ENVIRONMENTAL HEAT AND HUMIDITY TOLERATED BY ACCLIMATIZED, NORMAL, YOUNG MEN WORKING IN HOT ENVIRONMENTS

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Project Nos. 2-11, 2-13, 2-17

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ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

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THE UPPER LIMITS OF ENVIRONMENTAL HEAT AND HUMIDITY TOLERATED BY ACCLIMATIZED, NORMAL, YOUNG MEN WORKING IN HOT ENVIRONMENTS.

1. PROJECT: No. 2 - Operations at High Temperatures; Sub-Projects 2-11, Influence of High Temperatures upon the Efficiency of Personnel; 2-13, Effect of Training upon the Efficiency of Performance at High Temperatures; 2-17, Study of the Physiologic Effects of High Temperatures.

a. Authority - Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, File 400.112/6 GNOHD, dated 21 September 1942.

b. Purpose - To determine the upper limits, and the safe limits, of temperature and humidity at which acclimatized, normal, young men can work in hot environments.

2. DISCUSSION:

a. Previous reports (1, 2, 3, 4) from this Laboratory have described the physiologic changes and readjustments which occur in normal young men working in both dry and humid hot environments which simulated the severest natural climates. Principles for the management of men in such environments have been formulated. In hot climates, combat vehicles, particularly when closed, develop internal environments exceeding in severity all naturally existing climates. It became necessary, therefore, to study men working in such excessively hot and humid environments and to determine the upper environmental limits in which work is still readily and efficiently performed and those limits beyond which work is either impossible, or if performed, then inefficiently and with undesirable physiologic disturbances. A knowledge of such safe and maximal environmental limits serves two practical purposes: (a) it indicates what may be expected of men working in a given hot environment, (b) it forms a basis for the evaluation of the heat problem in certain combat vehicles.

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1. Results of Desert Field Study, Project 2 (2-8), File 724.3, 20 October 1942.
2. Studies of Men in Simulated Desert Heat, Project 2 (2-11, 12, 13, 17), File 727-2, 3 April 1943.
3. Studies of Men in Simulated Jungle (Humid) Heat, Project 2 (2-7, 11, 13, 15, 17, 19), File 727.3, GNOML, 18 October 1943.
4. Determination of Water and Salt Requirements for Desert Operations, Project 2 (2-6), File 333.34, GNOML, 20 May 1943.

b. In a study of the upper environmental limits for work in hot environments, many factors need to be controlled: (1) the degree of acclimatization of the men to heat, (2) the nature of the environment, (3) the nature of the work, (4) the physical and mental fitness of the subjects, (5) the clothing worn, (6) the salt and water intake, (7) the criterion of limit, i.e., the condition of the men during and on completing the work. Each of these factors may vary widely. The state of acclimatization may vary from full acclimatization to none at all. The environment may vary in temperature, humidity, air movement, and radiant energy transmitted. The work may vary widely both in severity and in duration. Large variations in physical fitness occur between men and groups of men. Many types of clothing may be worn and the effect exerted by a garment need not be the same in different environments. Schedules of water and salt intake range from complete restriction of water to full replacement of the amounts lost. The condition of the men on completing the work may vary from exhaustion to ability to continue indefinitely. A change in any factor may alter completely the upper environmental limit.

Two conclusions are at once apparent: (1) the number of possible conditions exceeds the present possibilities of study, (2) a practical, even though arbitrary, set of conditions must be chosen and standardized for investigation. In this study the combination of variables chosen was based on the principles that the environment be as simple as possible; the work be significant to the Army in type, severity and duration; the men be so managed that they have every opportunity to complete the work. The conditions of this study were as follows: (1) the men were first acclimatized to simulated desert (dry) and jungle (humid) heat; (2) the environment varied only in dry bulb and wet bulb temperature, no additional radiant energy was supplied, the air movement was that created by the men marching in single file at 3 miles/hour; (3) the work consisted of four hours of continuous marching on a level at 3 miles per hour with 20 pound pack (approximately 300 Calories/hour); (4) physical fitness was that of healthy garrison soldiers; (5) no clothing was worn other than socks and shoes; (6) water, salted to 0.1% with table salt, was given whenever requested and the men were urged to drink liberally; (7) the men were required to finish the work "fit to fight."

3. CONCLUSIONS:

The data and conclusions of this report apply only to upper environmental limits determined under the standard conditions above described and for environments in which the dry bulb temperature ranged between 93°F. and 121°F. and the wet bulb temperature between 90°F. and 96°F.

a. Within the range of environments here studied, the wet bulb temperature is the limiting factor which determines the ability of men to work in hot environments. The dry bulb temperature exerts only a minor influence in this regard.

b. As the upper environmental limits are approached, a narrow range of wet bulb temperature separates environments in which work is relatively easy from those in which it is impossible. At a given dry bulb temperature, this range is 4°F. to 5°F.

c. When the wet bulb temperature is below 91°F., men work easily, efficiently, and with only mild physiologic changes.

d. At wet bulb temperatures between 91°F. and 94°F., men are capable of prolonged, moderately hard work but they now work with difficulty, lose vigor and alertness, sustain undesirable physiologic changes and may even suffer illness.

e. Moderately hard work at wet bulb temperatures of 94°F. and higher leads rapidly to total disability in most men, with excessive, and often disturbing, physiologic changes. Approximately one hour of sustained work is tolerated by most men; those who work longer do so inefficiently and with marked physiologic disturbances.

f. The limiting wet bulb temperatures for each of the above three types of performance (c, d, e) is slightly (approximately 2°F.) higher at dry bulb temperatures below 100.0°F. than at a dry bulb temperature of 120°F.

	LIMITING WET BULB TEMPERATURE °F.		
	Relatively Easy	Difficult	Impossible
Completely Saturated Environment	92.5	94	96
120°F. Dry Bulb	90	92	94

g. At the upper environmental limits, sweating is extremely profuse; most men average 2.25 liters per hour and some reach 3.5 liters per hour.

h. Acclimatized men working above the upper environmental limits undergo marked physiologic changes and develop undesirable, frequently disabling, symptoms.

(1) Heart rates of 150 to 180 beats per minute.

(2) Rectal temperatures of 102.0°F. to 103.5°F.

(3) Average, weighted, skin temperatures approaching 101°F.

(4) Of the symptoms, the most frequent are severe and protracted headache, nausea, severe weakness, vertigo, dyspnea, abdominal cramps, copious vomiting, precordial pain, paraesthesias, stumbling and staggering, disorientation and collapse with syncope.

4. RECOMMENDATIONS:

a. The essential information in this report be made available in the form of a circular to:

(1) All line and medical officers, particularly of armored units, operating or preparing to operate in hot climates.

(2) Agencies concerned with the design and manufacture of closed combat vehicles.

b. Men working in hot environments which approach the upper limits be allotted and encouraged to drink from 2 to 3 quarts of water per hour during the period of work.

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#1 - Appendix
#2 - Tables 1 thru 5
#3 - Charts 1 thru 16

APPENDIX

A. SUBJECTS, EXPERIMENTAL CONDITIONS AND PROCEDURES

This study was conducted in the same general manner as the previously reported studies on acclimatization of men to dry and humid heat (2, 3). All observations were made during March, April and May in the Laboratory Hot Room.

1. Environments

In all parts of the working area, the dry bulb and wet bulb temperatures were maintained within ± 1°F. of the desired temperature. Psychrometric measurements were made at least every 15 minutes (often every 5 to 10 minutes) by means of a sling psychrometer. Twelve to fifteen hours before the men began to work, the desired environmental conditions were initiated in the hot room. This permitted the walls and floor to approach more closely the air temperature. Even so the walls were 2°F. to 5°F. cooler than the air and the floor 10°F. to 20°F. cooler than the air. No additional radiant heat was supplied. The air in the room was mildly turbulent throughout and without pockets. Wind velocity was not measured but was essentially that produced by the movement of the men marching single file at 3 miles/hour.

Approximations of the mean air movement on the men during work and of the mean radiation temperature of the room (average temperature of walls, floor and ceiling) were calculated from the cooling curves of two heated cylinders wheeled along with the marching men. One cylinder was highly burnished (emmissivity 0.025), the other blackened (emmissivity 0.94). Since the convective heat exchange of the cylinders is a function of wind velocity, the air movement experienced by the working men can be expressed by a coefficient of convection exchange. This was similar for all of the environments studied and ranged from 6 to 7 $Cal/M^2/Hr/^oF$. The mean radiation temperature of the room was always less than the air temperature; 2°F. to 3°F. lower at ambient temperatures under 100°F., and 7°F. to 9°F. lower at an ambient temperature of 120°F.

Table I indicates the environments in which the men worked; Chart 1, the sequence of these environments and the duration of stay in each. Of the 18 environments studied, four (4) are excluded from consideration in this report either because the duration of study in the environment was inadequate or because the environment was too mild for consideration in a problem dealing with upper environmental limits. For the 14 environments which form the basis for this report, the dry bulb temperature ranged from 92.6°F. to 120.5°F. and the wet bulb temperature from 89.5°F. to 96°F. The men slept in their own barracks, the temperature of which varied from 55°F. to 73°F.

On at least one day each week, the men worked in the relatively easy environment of D.B.* 93°F., W.B.* 92°F. This constituted a base environment and served two purposes. First, it served as a reference environment for the determination of the constancy of the reactions of the men; i.e., that they had not altered (deteriorated) in their reactions to a given environment during the study.

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* Henceforth D.B. will be used to signify dry bulb temperature and W.B. wet bulb temperature.

This was important since the measuring stick of this study was the reactions of the men. Secondly, it served as a recovery environment. After several days of marked physiological disturbances, and even disability, in the more severe environments, the men required a relative rest in a more easy, yet stress producing, environment before re-exposure to the more difficult environments.

2. Experimental Subjects

Thirteen (13) enlisted white men volunteered as subjects and were studied simultaneously. Their ages varied from 18 to 30 years. Only four were older than the average group age of 21.6 years. Their weights ranged from 138 to 183 pounds (average 165 pounds); their heights from 66 to 72 inches (average 69 inches); their surface areas from 1.73 to 2.00 square meters (average 1.89 sq. M.); their duration of military service from 7 to 108 months (average 22.7 mo.). All men were normal and healthy but in different states of physical fitness.

3. Activity

For one week the men underwent preliminary training (marching) until they were able to march with ease 12 miles a day at 3 miles per hour, carrying a 20 pound pack. This toughened the feet, accustomed the men to the required work and produced a more uniform state of physical fitness in all men. After the preliminary training and before undertaking the actual study of the upper environmental limits, the men were thoroughly acclimatized to dry (simulated desert) and humid (simulated jungle) heat of the type described in previous reports (2, 3). For six days they worked in an environment with D.B. 120°F. and W.B. 79°F., for 2 days at D.B. 90°F. and W.B. 89°F., and one day at D.B. 92.5°F and W.B. 91°F.

During the study of the upper environmental limits, the standard day consisted of 8 to 9 hours spent in the hot environment according to the following schedule: 0700 hours to 1200 hours, marching; 1200 hours to 1300 hours, lunch; 1300 hours to 1500 or 1600 hours, observations on resting men. Following the afternoon's observations, the men returned to their quarters, were restricted to the Post, and were bed-checked at 2200 hours.

The 13 men worked simultaneously, marching single file around a 77 foot track at 3 miles per hour. To permit the taking of data, the men started in a staggered fashion. Each man carried a 20 pound pack. This work rate was previously determined to amount to a total energy expenditure of approximately 300 Calories per hour. The standard work consisted of 4 hours of continuous marching without rest and without leaving the hot environment. (Even periods as short as 5 minutes in a temperate environment were found to improve the work performance and to decrease the physiologic disturbances.) At hourly intervals (more frequently when men became ill), the men halted and stood erect for 2 to 3 minutes while their heart rates, rectal temperatures and respiratory rates were determined.

In the more severe environments several days were required to bring the men to their peak performance. At first they worked for 2 hours in the morning and 2 hours in the afternoon before attempting the standard 4 hours of continuous effort (Chart 1). They then worked in the same environment repeatedly (up to 6 days) in order to give them every opportunity to achieve their best performance (Chart 2).

In easier environments, where work was performed with relative ease, the men worked for only one or two days.

4. Clothing

Most men wore only light wool socks and service shoes. A few wore, in addition, cotton shorts which became completely wet and dripped continually after 5 to 10 minutes of effort.

5. Food and Water

The food consisted of field rations, type A, obtained from the company mess. Only the mid-day meal was eaten in the hot environment, the other two meals at the company mess. The amount of food eaten was not measured. It varied, and depended on whether the environment made the men ill or not.

All water drunk in the hot room was salted (final concentration 0.1%) and carefully measured. The men were encouraged to drink and were given as much water as they desired whenever they requested it. Except in the most severe environments, the water intake during work approximated the sweat loss. In their own quarters, the men drank tap water.

6. Observations on the Men

Records were kept of the symptoms, complaints, and general appearance of the men during work. Immediately before beginning to work each man undressed completely, urinated, dried off the sweat and was carefully weighed (within 10 grams). At the beginning and end of each hour of work, the heart rate, rectal temperature, and respiratory rate were determinedwith the subjects standing erect. While in the hot environment all water drunk, urine voided and gastric contents vomited were carefully measured and recorded. The skin temperatures of 6 areas of the body (cheek, chest, palm, forearm, thigh and calf) were determined radiometrically immediately on completion of the work; the subjects were supine and unclothed and the sweat was not disturbed. As quickly as possible thereafter, the final weights were determined under the same conditions as the initial weight. The weighing was done in an adjacent control room; all other measurements were made in the hot environment.

The order of the observations was as follows: initial weighing; initial heart rate, rectal temperature and respiratory rate; hourly heart rate, rectal temperature and respiratory rate, final skin temperature; final weighing.

Whenever disability forced a man to discontinue marching before the required time, the final observations were immediately made and the time recorded. No man was allowed to discontinue work unless objective indications necessitated it.

B. GENERAL RESULTS

Only the averaged data for the group (13 men) are considered and in the following charts the plotted points represent this average. This decision was made because the group is a more representative and uniform unit than an individual subject. The data are those for the most representative (usually the last) day in each environment. This gives the best performance in each environment and excludes the observations made when the men were adapting themselves to a new environment.

Chart 2 indicates that even previously acclimatized men require a period of several days to adapt themselves to a new environment before their responses in it become standardized and representative. As a more severe environment is entered, the process of acclimatization to heat is repeated.

The total performance (work accomplished, subjective reactions, and physiologic changes) of the men in the fourteen environments fell into three distinct and readily separable groups. In defining these three types of performance, only the averaged performance for the group is considered

In the first type of performance, the men worked easily and without effort or complaints. All men finished 4 hours of continuous marching and on its completion were alert and fresh and seemingly capable of continuing the work indefinitely. The physiologic disturbances at the end of the 4 hours were mild and within the range ("acceptable") previously encountered in acclimatized men working in desert or jungle heat; viz. rectal temperature 101°F. or less and heart rate 130 per minute or less. Environments in which this type of performance was encountered are hereafter termed "relatively easy." These environments and the data obtained in them are represented by open circles (○) in all charts.

In the second type of performance all men still finshed 4 hours of continuous marching, but with much effort and many complaints. Rarely a man was forced to drop out in the fourth hour. There were frequent requests to discontinue before the required time. Some men had to fight to finish, and many were able to do so only under the exhortations, blandishments or threats of the officers in charge. Complaints of headache, fatigue, dizziness, and nausea were common. Occasionally men vomited. On completing the work most men were very tired; half of them probably could have continued, the other half probably not. The physiologic disturbances at the end of 4 hours of work were greater ("undesirable") than those usually encountered in acclimatized men working in desert or jungle heat. The rectal temperatures were between 101°F. and 102°F. and the heart rates between 130 to 145 per minute. Environments in which this type of performance was encountered are hereafter termed "difficult." These environments and the data obtained in them are indicated in all charts by a closed circle (●). A few of the best men in the group had no greater difficulty in these environments than in the relatively easy ones.

In the third type of performance, the group as a unit never finished more than one hour of continuous marching. The men worked with great effort and had to be continually goaded to maintain the work rate. Approximately one-third of the men completed 2 hours of work and only two or three men finished the 4 hours of continuous effort. Undesirable symptoms began to appear after 30 minutes of walking, progressed rapidly and soon most of the men were completely disabled. There were frequent complaints of violent throbbing headache, dizziness, marked fatigue with inability to keep the pace, difficulty in breathing, coronary type of precordial pain and substernal distress, abdominal cramps and nausea. Men became glassy-eyed, stumbled and weaved in their gait and bumped into the walls. Some men fell into corners of the room, vomiting copiously (as much as 1.5 to 2 liters); others became disorientated and could not read the time correctly or even repeat their serial numbers; still others were "out-on-their feet" and did not recall what had happened until revived several minutes later in the adjoining cool room; a few collapsed outright. The physiologic disturbances were "excessive", and at times disturbing. Usually the rectal temperatures were over 102°F. and

the heart rates exceeded 150 per minute. Environments in which this type of performance was encountered are hereafter termed "impossible." These environments and the data obtained in them are indicated in all charts by an x (x). Only two or three men were able to complete 4 hours of work in some of the impossible environments. They did so without undue effort and without severe complaints.

In the difficult environments, most men experienced a reaction like "second wind" during the second hour of work. At the end of the first hour most men looked ill, worked with difficulty and experienced distressing symptoms. A few vomited, others requested permission to discontinue. The heart rates tended to be higher than expected from the rectal temperatures. Toward the end of the second hour the men began to improve. They looked and felt better and complained less of symptoms. Thereafter they usually improved progressively and finished 4 hours of work in fairly good condition. Both the subjects and observers agreed that they were better in all respects at the finish than they had been during the second hour. An accompanying slight decrease in heart rate occurred in many men, but the rectal temperature continued to rise slowly. Apparently the men felt worse when their physiologic disturbances were building up toward an equilibrium and improved as that equilibrium was achieved.

The same phenomenon was experienced by the few men who finished 4 hours of work in some of the impossible environments. However, in these environments most men showed no improvement with continued work, only progressive deterioration both subjectively and objectively until forced by disability to discontinue work.

In determining whether an environment was relatively easy, difficult, or impossible, more weight was given to the ease of performance, the amount of work accomplished, the appearance of the men and their symptoms than to the physiologic changes. It was, nevertheless, fully recognized that work in the presence of marked physiologic changes is undesirable and at times impossible.

In previous studies on the reactions of men in simulated desert (dry) and simulated jungle (humid) heat, it was pointed out that the changes in the heart rate, rectal temperature and blood pressure need not always parallel, nor indicate, the actual performance. The present study confirms this conclusion. It was not unusual for men to be completely disabled at a time when their rectal temperatures and heart rates would not in themselves have warranted discontinuance of work. These rectal temperatures and heart rates were no higher, and at times even lower, than those obtained, (1) in other men at the end of longer periods of effort or (2) in the same men at the end of 4 hours of marching in a less severe environment. Factors other than rectal temperature, heart rate, sweat loss, or skin temperature had induced disability.

This is indicated well in Table II, the data for which was obtained when the men either fell out or finished work in the impossible environment of D.B. 96°F. and W.B. 96°F. Certainly the ability to finish 4 hours of work was not dependent upon the smaller physiologic disturbances. Indeed, the highest rectal temperatures, and skin temperatures, were obtained in the men who worked the longest and there was no relationship between the heart rate or the rate of sweating and the duration of effort.

The responses of the group in the various environments are indicated largely by charts of heart rate, rectal temperature, sweat loss and skin temperature. The

data upon which these charts are based are presented in Tables III, IV, and V for relatively easy, difficult and impossible environments respectively. It is to be understood that these few physiologic functions serve only as gross indices of the total reaction to the environment. Attention should be given to the symbols (o, •, x) by which these functions are plotted and the results analyzed in terms of the three previous paragraphs describing the general reactions in relatively easy, difficult and impossible environments.

C. ANALYSIS OF ENVIRONMENTS

1. Equivalent Environments

Chart 3 is a psychrometric chart upon which are plotted the fourteen environments in which the men worked. The rating of relatively easy (°), difficult (•), or impossible (x) given each environment represents the best overall evaluation on the basis of the principles already discussed. Environments having the same rating have a linear distribution. This gives three lines, each of which represents environments of equivalent severity for working men; the lines of equivalent environments in which work is impossible, difficult, and relatively easy. The three lines are parallel to each other and close together, leaving narrow bands between environments in which work is relatively easy and those in which it is difficult or impossible. Although these lines do not parallel a psychrometric function, they follow the wet bulb temperatures most closely and cut across lines of dry bulb temperature and relative humidity over wide ranges.

In this and subsequent charts the line of environments in which work is difficult indicates the upper environmental limits for men working as here described. This limit may be expressed as equivalent to a saturated atmosphere at 94°F. Since work in difficult environments is not easily maintained, is performed inefficiently and with effort, and leads to symptoms in some men, the practical, and safe, upper environmental limit should not exceed the line of equivalent environments in which work is relatively easy. This limit may be expressed as equivalent to a saturated atmosphere at 92°F. In these environments, men work cheerfully, efficiently and effectively.

2. Relative Humidity

Chart 4 indicates the role of relative humidity in determining the tolerability for work in hot environments. As expected, the lower the dry bulb temperature, the higher the tolerable humidity. At any given dry bulb temperature, the range of relative humidity between relatively easy and impossible environments is quite narrow and slightly narrower at the higher dry bulb temperatures than at the lower ones. The line of difficult equivalent environments again indicates the upper environmental limits for work in hot environments. Work cannot be performed in environments above and to the right of this line and is readily accomplished in the zone below and to the left of the relatively easy line.

This chart shows the completely saturated environment beyond which work cannot be performed, 94°F. for both dry and wet bulb temperatures. The sharpness of this upper limit is indicated by the fact that an increase of 3.5°F. (from 92.5°F. to 96°F.) changes the environment from one in which work is relatively easy to one in which it is impossible.

3. Wet Bulb Temperature

The wet bulb temperature is the chief limiting factor which determines the ability of men to work in hot environments which approach human tolerance for work. This is indicated in Chart 5. On approaching the upper environmental limits a small increase (2°F.) in wet bulb temperature, at any given dry bulb temperature, changes an environment in which work is relatively easy into one in which work is difficult. Another small increase (2°F.) makes work impossible. The increase in wet bulb temperature required to produce these changes is the same in the hotter (120°F.) relatively dry environments as in the less hot (D.B. 96°F.) but more humid environments. As a consequence, the lines of equivalent environments are approximately parallel and equidistant. However, they are not horizontal. This means that a single wet bulb temperature does not serve as the limiting factor at all temperature ranges. The limiting wet bulb temperatures decrease slightly as the dry bulb temperatures rise, causing the lines of equivalent environments to slope toward the abscissa at their upper (hotter) ends. At a dry bulb temperature of 120°F., the limiting wet bulb temperatures are 2-3°F. lower than at environments with dry bulb temperatures below 100°F.

The upper environmental limits for work in hot environments (line of difficult equivalent environments) may be expressed as wet bulb temperatures; 94°F. for a completely saturated environment and 92°F. at a dry bulb temperature of 120°F. Corresponding, but more practical and safe limits (those of relatively easy environments) are 92°F. and 90°F. respectively.

In contrast to the wet bulb temperature, the dry bulb temperature influences the upper environmental limits to a much lesser degree. Thus, at a given wet bulb temperature, the dry bulb temperature can vary over a wide range (93°F. to 121°F.) without causing much change in the environmental rating (Chart 5).

4. Effective Temperature

Since a single wet bulb temperature fails to determine the upper environmental limit for work in all hot environments and since the wet bulb temperatures of equivalent environments tends to decrease as the dry bulb temperatures increase, the effective temperature suggested itself as an index of the severity of environments for working men. Although designed as a comfort scale based on subjective comparisons of environments, the effective temperature scale has more recently been applied to working men. Chart 6 indicates that the effective* temperatures for equivalent environments are not constant but increase slightly as the dry bulb temperatures of the environments rise. These increases are small and approximately the same for the three categories of equivalent environments so that the lines for equivalent environments tend to remain essentially parallel. However, the three lines do converge slightly at environments with higher dry bulb temperatures. As with the wet bulb temperature, a change of a few degrees

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* Effective temperatures were determined from ASHVE comfort data for partially clothed, resting men at a wind velocity of 200 ft./min.

in the effective temperature, at a given dry bulb temperature, influences markedly the ability of men to work in hot environments which approach upper tolerable limits.

No single effective temperature serves as an index of the upper environmental limit for all hot surroundings. The upper limit (line of difficult equivalent environments) of effective temperature for work in hot environments was 92.8°E.T. in the completely saturated atmosphere and 95.6°E.T. at dry bulb temperatures of 120°F. Corresponding, and more practical limits, (relatively easy environments) are 91°E.T. and 94.4°E.T. respectively.

D. ANALYSIS OF THE RESPONSES OF THE MEN

The performance and physiologic responses of the men in the different hot environments give further support for the separation of the environments into three categories: relatively easy, difficult, and impossible.

1. Performance

From the performances of the group in each of the environments within an equivalent category (easy, difficult, and impossible), the average performance for each of the three categories were obtained and are plotted in Chart 7. The curve in the lower half of Chart 7 indicates what percent of the men who started are still walking at any given time. The curve in the upper half of Chart 7 indicates the percent of the total required man-hours of work actually performed from the start of work to the end of each hour. This was obtained by determining the total man-hours of work performed from the start to the end of each hour, dividing by the man-hours of work expected if all men had worked continuously from the outset, and multiplying by 100.

In the relatively easy and difficult environments, 100% of the men who started finished 4 hours of continuous work (lower half of chart) to give a group performance of accomplishing 100% of the required man-hours of work (upper half of chart).

The lower half of the chart indicates the disability curve of men working in impossible environments. All men finished 1 hour of work. Only one-third of the men completed 2 hours of work, one-seventh 3 hours, and less than 10% were marching at the end of 4 hours. Thus, the group completed 100% of the required one-hour's work, only a little more than 75% of the total required work for 2 hours, about 60% of the required 3 hours' work, and less than 50% of the required 4 hours' work (upper half of chart). This is on the basis that men who fall out, remain out, and do not resume work after a rest period.

2. Rectal Temperature

The average rectal temperatures for the group at the end of each hour of work in each of the fourteen environments is plotted in Chart 8. In all environments, the rectal temperature rises rapidly during the first hour, less

rapidly during the second hour, then progressively more slowly apparently approaching equilibrium values. At the end of each hour of work, the rectal temperatures for environments with the same rating (relatively easy, difficult, and impossible) are distributed throughout a zone which is readily separable from the rectal temperatures for environments in the other two ratings. The values are lowest for environments in which work is relatively easy (o), and highest for environments in which work is impossible (x). At the end of 4 hours of work, the rectal temperatures for the relatively easy environments (o) are in the acceptable range (under 101°F.), for the difficult environments (•) in the undesirable zone (101°F. and 102°F.) and for the impossible environments (x) in the excessive zone (above 102°F.). It must be remembered that after the first hour the number of men who contribute to the rectal temperatures for the impossible environments are reduced in number in accordance with the performance curve in the lower half of Chart 7.

At the end of the first hour of work, the rectal temperatures in the difficult environments are still within the acceptable range. As work continues the temperatures rise, reaching the undesirable zone by the end of the fourth hour. On the other hand, the rectal temperatures after one hour of work in the impossible environments are already undesirable and become excessive after an additional hour of work. From the standpoint of the heat gained by the body, difficult environments are acceptable for one hour of work but not for 4 hours of work; whereas impossible environments are undesirable for even such short periods as one hour.

3. Heart Rate

The average heart rates for the group during work in each of the fourteen environments are plotted in Chart 9. The heart rates at the end of each hour of work for all environments with the same rating fall into a band or zone which is separable from the zones into which the heart rates for the other two ratings fall. The heart rates for the impossible environments are in the excessive zone (above 145 per min.), those for the difficult environments fall in the undesirable zone (131 to 145 per min.), while in the relatively easy environments, the heart rates are in the acceptable zone (below 130 per min.). The heart rates in all environments increase markedly during the first hour of work. Unlike the rectal temperatures, they tend to level off after the first hour and frequently hold these levels for the next 3 hours.

Here again, the men who contribute to the average heart rate in the impossible environments after the first hour are reduced in number in accordance with the disability curve in these environments (Chart 7, lower half). This accounts for the apparent decrease in the heart rates in the impossible environments after the first hour, since only the best men (some with lowest heart rates) are still working at these times.

In one instance, the average heart rate in a relatively easy environment (D.B. 120°F., W.B. 90°F.) rose above the acceptable zone into the undesirable and excessive zones. On the evening before this experiment the men were paid. Discipline in the barracks failed and there ensued a beer-party lasting well into the night. This may account for the unexpectedly high cardiac rates the next day. It is of interest that the rectal temperatures remained low and did not follow the heart rates.

4. Skin Temperature

Equivalent environments proved to be physiologically equivalent when considered from the standpoint of the approximately equal changes they induced in the work performance, rectal temperature, and heart rate. However, equivalent environments appeared less equivalent physiologically when considered with regard to the changes induced in the skin temperature and in the sweating rate.

In normal temperate environments, wide differences may exist between the skin temperatures of the various parts of the body. These differences disappear after work in hot environments and the skin temperature becomes almost identical in all parts of the body. The temperatures here reported are the average weighted skin temperatures for the body as a whole, calculated according to the weighting formula of Hardy and DuBois. In the relatively easy and difficult environments, the skin temperatures are the group averages at the end of 4 hours of work; in the impossible environments, they are the averages for the group at the time of cessation of work regardless of the duration of effort. Chart 10 indicates the wide scattering of the skin temperatures for equivalent environments with the same rating and the considerable overlapping of the values with one rating by those for the other two ratings. In only a very general way, indicated by the averaged skin temperatures for each of the 3 ratings of equivalent environments, the skin temperature is highest (average 100.3°F.) for the impossible environments, intermediate (average 99.1°F.) for the difficult environments and lowest (average 98.3°F.) for the relatively easy environments.

Since only a few men finished 4 hours of work in the impossible environments, the skin temperatures in these environments may be underweighted and conceivably could have been higher had the men been able to work as long as they did in the relatively easy and difficult environments.

Chart 11 indicates that the externally imposed thermal load, i.e., the dry bulb temperature of the environment, exerts a definite effect on the skin temperature and that this factor may be more significant in determining the final skin temperature than is the severity of the environment as indicated by the scale of equivalent environments. The final skin temperature shows a definite tendency to increase directly with the dry bulb temperature of the environment, irrespective of its severity rating. For example, in the relatively easy environment of D.B. 120°F., W.B. 90°F., the skin temperature (100.2°F.) is higher than it is (99.0°F.) in the impossible environment of D.B. 96°F., W.B. 96°F. It is, nevertheless, true that at a given dry bulb temperature, the final skin temperatures in the impossible environments tend to exceed those in the difficult and relatively easy environments, often by rather small amounts. (The line in Chart 11 is fitted by the method of least squares and $r = .68$.)

5. Weight (sweat) Loss

The average weight (sweat) lost per hour per man during work in each of the 14 environments is plotted in Chart 12. The data gives the weight (sweat) loss per hour regardless of the duration of effort. As with the skin temperature, there is a wide scattering of the values for environments having the same

equivalent rating. There is also considerable overlapping of the values for environments with one rating by values for environments with the other two ratings. This is less pronounced than with the skin temperature and there is a fairly good separation of the sweat losses in the relatively easy environments from those in the impossible environments.

The weight (sweat) loss in the relatively easy environments varied from 1056 c.c. to 1687 c.c. (average 1433 c.c.), in the difficult environments from 1241 c.c. to 1979 c.c. (average 1560 c.c.), and in the impossible environments from 1676 c.c. to 2689 c.c. (average 2289 c.c.). These are average values for the group. Individual losses fell outside of these values in both directions.

Chart 13 indicates that a fairly good fluid balance was maintained in all environments. This was achieved by the men voluntarily drinking water in amounts approximating their sweat losses. The average urine output was approximately the same (40 c.c. to 80 c.c. per hour) in all environments and so small in quantity as to be insignificant in the face of the much larger sweat losses and water intakes.

The amount of water lost through sweating in the more severe environments can be appreciated best by relating it to the total amount of body water and its partitions. A sweat loss of 2.25 liters per hour is common for men working in impossible environments and for many men working in difficult environments. An average man has approximately 3.5 liters of blood plasma of which about 3.2 liters are free water. Therefore, men easily lose in an hour through sweating a volume of water approximating 70% of the free water of the blood. The more profusely sweating men have lost from 3.3 liters to 3.9 liters of sweat in an hour, amounts equalling and exceeding (120%) the total blood water. The highest sweating rate encountered was 4.2 liters an hour. Men have completed 4 hours of work in good condition while sweating at rates of 3.0 liters per hour, a loss of 12 liters of fluid in the 4 hours. This is an amount equal to approximately four times the blood water, and about 3/4 to 4/5 of the total extracellular fluid, which approximates 14 to 15 liters. It also equals approximately 25% of the 48 to 50 liters of total body water of a 70 Kg. man. (70% of the body weight in water).

Since the men drank water in amounts approximating the sweat lost (Chart 13), voided but small amounts of urine (40 - 80 c.c./hr.), and did not gain weight, they apparently transferred from their gastrointestinal tracts, through the blood stream, to the sweat glands and out of them the large quantities of fluid above described. The largest fluid turnover encountered was in a man who drank and sweated 18 liters in a little less than 8 hours, 12 liters during the morning work period, 3 liters during the mid-day interval and 3 liters during the afternoon resting period. In the face of the turnover of such large volumes of water between the gastrointestinal tract and skin, the men continued to work surprisingly well day after day.

The ingestion and secretion of such large volumes of fluid raises the question of changes in the plasma electrolytes and in the concentration of the cellular elements of the blood. Analyses of venous blood before work, after one hour of work and again when the men completed four hours of work or fell out, revealed only small changes in the cellular volume and in the concentration of

electrolytes, even in the most severe environments. Hemo-concentration was absent or slight. On the completion of work, the serum sodium, potassium, and chloride concentrations decreased slightly, less than 5 mEq/L and with the final value still within the normal range. The blood pH usually increased .02 - .05 pH units. Where tachypnea and hyperpnea induced alkalosis, the pH increase was somewhat greater. In these instances the venous CO_2 content fell considerably, otherwise only slightly. There were no significant differences between the values for men who were forced to discontinue and men who completed 4 hours of work.

In environments beyond the upper environmental limits, the profuse sweating appeared to be responsible for disability in a number of men. In these environments, the following sequence of events was frequently encountered. The profuse sweating soon led to thirst and men began to drink copiously. With continued sweating, the need for water also continued and the thirst persisted, or even increased, in spite of huge intakes of water. Men could not refrain from drinking. Symptoms of an overloaded stomach developed and were added to the miseries of a seemingly unquenchable thirst. Men became sick, bloating and nausea appeared, then abdominal cramps and finally repeated vomiting with total disability. Apparently the loss of water through sweating exceeded the absorptive capacities of the gastrointestinal tract. As a result, fluid was not absorbed from the gastrointestinal tract as rapidly as it was introduced in response to the need (thirst) for water. Vomiting ensued. This sequence was not encountered in difficult or relatively easy environments where fluid intakes of 2.0 to 2.5 liters per hour were common. It occurred as the fluid intakes and sweat losses approached or exceeded 3 liters per hour.

E. ANALYSIS OF PHYSIOLOGIC CHANGES

1. Physiologic Basis for the Narrowness of Upper Environmental Limits

It has already been pointed out (Charts 3 through 6) that at the upper environmental limits narrow zones separate the three equivalent environments, relatively easy, difficult, and impossible. Charts 14 (completely saturated environments) and 15 (hotter and more dry environments) indicate that this narrow separation is based on physiologic changes as well as performance and that the lines of equivalent environments govern physiologic changes as well as the capacity for work. In both types of environments (both charts), the rectal temperature, heart rate, skin temperature and the rate of sweating show increases of progressive severity as one passes through the narrow bands separating the relatively easy from the difficult and the difficult from the impossible environments. The heart rate in one relatively easy environment (D.B. 120°F., W.B. 90°F.) in chart 15 fails to follow the orderly sequence of change. This observation was made on the day after the pay-day-beer-party already mentioned. It may not, therefore, be representative.

2. Relative Significance of Dry and Wet Bulb Temperatures

Charts 14 and 15 also indicate that at the upper environmental limits, the wet bulb temperature determines not only the performance, but also the magnitude of the physiologic disturbances occurring in men working in hot environments. In both the completely saturated (Chart 14) and the hotter more dry (Chart 15) environments, successive rises of 2°F. in the wet bulb temperature of the environment

produce corresponding step-like increases in the severity of the physiologic responses. These small increases in the wet bulb temperature shift the heart rate and rectal temperature from acceptable to undesirable or from undesirable to excessive ranges. Note that in Chart 15 the dry bulb temperature of the environment remains constant as the wet bulb temperature increases by increments of 2°F.

If the wet bulb temperature is the environmental factor which determines the physiologic responses then at a constant wet bulb temperature considerable variation in the dry bulb temperature should be possible without altering the physiologic changes. Chart 16 lends support to this concept. In the two environments plotted, the wet bulb temperature was the same, 92°F., while the dry bulb temperature varied over 26°F., 93°F. in one environment and 119°F. in the other. In both environments, the average rectal temperatures, heart rates and sweating rates were very much the same at all corresponding periods. Only the skin temperature failed to behave in the same manner as the other three functions (see relationship of skin temperature to dry bulb temperature of environment). The day when the temperatures were D.B. 93°F., W.B. 92°F. was separated from the other day (D.B. 119°F., W.B. 92°F.) by only 4 days.

SUMMARY

This study has indicated that the wet bulb temperature of the environment is the most important and often the limiting factor in determining not only the performance of men in hot environments but also some of their physiologic responses. The following practical rules may serve as the basis for the management of acclimatized men working in hot environments; in surroundings in which the wet bulb temperature does not exceed 91°F. men will work easily, efficiently and effectively, and without heat casualty; when the wet bulb temperature is between 91°F. and 94°F., men will work with difficulty, inefficiently and often ineffectively, mild heat casualties may occur; at wet bulb temperatures exceeding 94°F., most men are incapable of sustained effort and those who work do so inefficiently and ineffectively. A high incidence of heat casualties (often severe) is to be expected.

It is reemphasized that the conclusions here presented pertain only to the standardized conditions of this study. Moreover the duration of exposure to any single environment was relatively short, a matter of several days to a week. It is not permissible, therefore, to predict the performance and reactions of men exposed daily for long periods of time (months) to some of the more severe environments here examined. Either improvement or deterioration of performance is possible. Some observations in the present study indicate that deterioration is the more likely. When men worked (and suffered disability) daily in the impossible environments, their performance, and particularly their morale and will-to-work, appeared to deteriorate with succeeding days. No such deterioration was evident when men worked repeatedly in the relatively easy environments. This is further evidence for accepting the line of the relatively easy equivalent environments as the practical, and safe, upper environmental limit for acclimatized men working in hot surroundings.

TABLE I

HOT ENVIRONMENTS IN WHICH ACCLIMATIZED NORMAL MEN WERE STUDIED

		Dry Bulb Temperature (°F.)	Wet Bulb Temperature (°F.)	Relative Humidity (%)	Effective Temperature (°E.T.)
Group I. Relatively Easy Environments*					
1	21 - April	92.6	92.4	100	91.0
2	29 - April	93.3	92.1	95	90.7
3	6 - April	94.1	92.1	93	90.9
4	25 - April	111.6	89.5	43	92.6
5	11 - May	120.6	89.8	30	94.4
Group II. Difficult Environments*					
1	28 - April	94.0	94.0	100	92.8
2	14 - April	100.0	94.2	81	94.1
3	13 - April	100.8	93.0	76	93.1
4	8 - April	106.4	92.5	59	93.7
5	13 - May	119.3	91.7	36	95.6
Group III. Impossible Environments*					
1	18 - May	96.1	95.9	100	95.3
2	22 - April	99.7	96.1	88	95.8
3	11 - April	106.2	95.0	67	95.8
4	20 - May	119.9	93.9	38	97.2
Group IV. Omitted from Consideration in This Study**					
1	31 - March	90.0	88.8	96	86.8
2	4 - May	114.2	93.1	46	95.6
3	9 - May	120.2	83.1	21	90.6
4	10 - May	120.2	87.6	28	93.1

*Basis of grouping explained later in text.

**Excluded from this report; insufficiently studied or too far below upper environmental limits to be included.

TABLE II

FAILURE OF PHYSICAL CHARACTERISTICS AND THE SEVERITY OF CERTAIN PHYSIOLOGIC CHANGES TO CORRELATE WITH THE CAPACITY TO WORK IN HOT ENVIRONMENTS. (DATA END OF WORK IN AN ENVIRONMENT OF D.B. 96°F., W.B. 96°F.)

Subject	Duration of Work* Hours	Rectal Temp. °F.	Skin Temp. °F.	Heart Rate Per Min.	Resp. Rate Per Min.	Sweat Loss Gr/Hr.	Height Inch	Weight Lbs.	Age Yrs.	Condition on Completion of Work
WIL	4	103.5	99.3	132	36	1240	68	138	19	Tired, walking easily.
STA	4	103.0	99.3	150	24	2530	72	177	21	Feels "fine."
KEI	4	103.0	99.1	162	40	2345	69	152	19	Tired; "fair."
SHE	1.7	103.0	99.1	159	36	3560	69	177	20	Weak, dizzy, exhausted.
ODO	1.5	103.5	99.9	159	24	3880	68	178	20	Dizzy, headache, exhausted.
PAR	1.3	102.5	99.1	159	22	3760	70	182	30	Dizzy, exhausted.
HOF	1.3	102.0	98.8	171	12	2425	71	162	28	"Can't breathe." "All in."
LAM	1	102.0	99.0	153	30	2510	68	160	19	Dizzy, headache, "All in."
MAY	1	102.0	99.1	156	44	2890	68	165	22	Dizzy, unable to go on.
BRI	1	101.8	98.6	168	24	2850	67	138	27	Dizzy, weak, "All in."
MOO	1	101.4	99.7	150	46	2830	70	164	18	Can't breathe. "All in."
ROC	1	101.4	98.6	159	30	2285	70	183	18	Stumbling, disoriented.
COH	1	101.3	98.4	159	32	2805	66	173	20	Chest pain, exhausted.

*All men who worked for less than 4 hours were unable to continue beyond the time recorded.

TABLE III

ENVIRONMENTAL AND PHYSIOLOGICAL DATA (AVERAGE FOR THE GROUP) DURING WORK IN "RELATIVELY EASY" ENVIRONMENTS

(Best Performance in Each Environment)

Date	5-11	4-25	4-6	4-29	4-21
Environmental Data					
Dry Bulb Temp. (°F.)	120.6	111.6	94.1	93.3	92.6
Wet Bulb Temp. (°F.)	89.8	89.5	92.1	92.1	92.4
Relative Humidity (%)	30	43	93	95	100.0
Effective Temp. (°E.T.)	94.4	92.6	90.9	90.7	91
Rectal Temperature (°F.)					
Initial	98.1	98.5	97.9	98.4	98.0
End of 1 Hour	100.0	99.6	100.0	99.9	100.0
End of 2 Hours	100.3	99.8	100.6	100.4	100.6
End of 3 Hours	100.5	100.2	101.0	100.7	100.7
End of 4 Hours	100.6	100.1	101.2	100.8	101.0
Heart Rate (Beats/min)					
Initial	105	97	93	89	95
End of 1 Hour	141	111	121	113	125
End of 2 Hours	140	118	121	117	121
End of 3 Hours	147	124	124	125	123
End of 4 Hours	150	121	132	125	128
Percent of Men Working (%)					
End of 1 Hour	100	100	100	100	100
End of 2 Hours	100	100	100	100	100
End of 3 Hours	100	100	100	100	100
End of 4 Hours	100	100	100	100	100
Final Average Weighted Skin Temp. °F.	100.2	99.7	97.7	98.2	95.5
Sweating Rate-Gram/Hour	1687	1469	1056	1616	1336

Incl. #2

TABLE IV

ENVIRONMENTAL AND PHYSIOLOGICAL DATA (AVERAGE FOR THE GROUP) DURING WORK IN "DIFFICULT" ENVIRONMENTS

(Best Performance in Each Environment)

Date	5-13	4-8	4-13	4-14	4-28
Environmental Data					
Dry Bulb Temp. (°F.)	119.3	106.4	100.8	100.0	94.0
Wet Bulb Temp. (°F.)	91.7	92.5	93.0	94.2	94.1
Relative Humidity (%)	36	60	75	80.5	100.0
Effective Temp. (°E.T.)	95.6	93.7	93.1	94.1	92.8
Rectal Temperature (°F.)					
Initial	98.4	98.4	98.0	98.4	98.4
End of 1 Hour	100.2	100.4	100.2	100.8	100.6
End of 2 Hours	100.8	101.0	100.5	101.7	101.6
End of 3 Hours	100.9	100.9	100.8	101.7	101.9
End of 4 Hours	101.0	101.4	101.5	102.0	101.9
Heart Rate (Beats/min)					
Initial	103	98	99	103	98
End of 1 Hour	131	130	130	146	138
End of 2 Hours	135	128	132	140	136
End of 3 Hours	139	128	135	134	139
End of 4 Hours	136	132	142	138	141
Percent of Men Working (%)					
End of 1 Hour	100	100	100	100	100
End of 2 Hours	100	100	100	100	100
End of 3 Hours	100	100	100	92	100
End of 4 Hours	92	100	100	92	100
Final Average Weighted Skin Temp. (°F.)	100.6	99.3	100.2	99.4	95.8
Sweating Rate-Gram/Hour	1979	1241	1372	1411	1799

Incl. #2

TABLE V

ENVIRONMENTAL AND PHYSIOLOGICAL DATA (AVERAGE FOR THE GROUP) DURING WORK IN "IMPOSSIBLE" ENVIRONMENTS

(Best Performance in Each Environment)

Date	5-20	4-11	4-22*	5-18
Environmental Data				
Dry Bulb Temp. (°F.)	119.9	106.2	99.7	96.1
Wet Bulb Temp. (°F.)	93.9	95.0	96.1	95.9
Relative Humidity (%)	38	66	87.6	100
Effective Temp. (°E.T.)	97.2	95.8	95.8	95.3
Rectal Temperature (°F.)				
Initial	98.4	98	98.4	98.3
End of 1 Hour	101.2	101.0	101.4	101.7
End of 2 Hours	102.2	102.3	102.7	102.6
End of 3 Hours	103.1	-	103.1	103.0
End of 4 Hours	-	-	-	103.2
Heart Rate (Beats/min)				
Initial	96	107	89	101
End of 1 Hour	145	159	145	156
End of 2 Hours	151	152	153	148
End of 3 Hours	144	-	163	149
End of 4 Hours	-	-	-	148
Percent of Men Working (%)				
End of 1 Hour	100	100	100	100
End of 2 Hours	31	54	50	23
End of 3 Hours	8	-	25	23
End of 4 Hours	-	-	-	23
Final Average Weighted Skin Temp. (°F.)	101.3	100.4	100.5	99.0
Sweating Rate-Gram/Hour	2651	1676	2140	2689

*Only 12 men started work on this day.

MEAN DAILY DRY BULB AND WET BULB TEMPERATURES OF ALL ENVIRONMENTS STUDIED AND THE WORK PERFORMED IN EACH, PRESENTED IN THE ORDER STUDIED

CHART I

CHART I

Incl. #2

CHART 2

MAXIMAL READJUSTMENT TO A NEW AND MORE SEVERE ENVIRONMENT REQUIRES SEVERAL DAYS REGARDLESS OF PREVIOUS ACCLIMATIZATION TO BOTH DRY AND HUMID HEAT

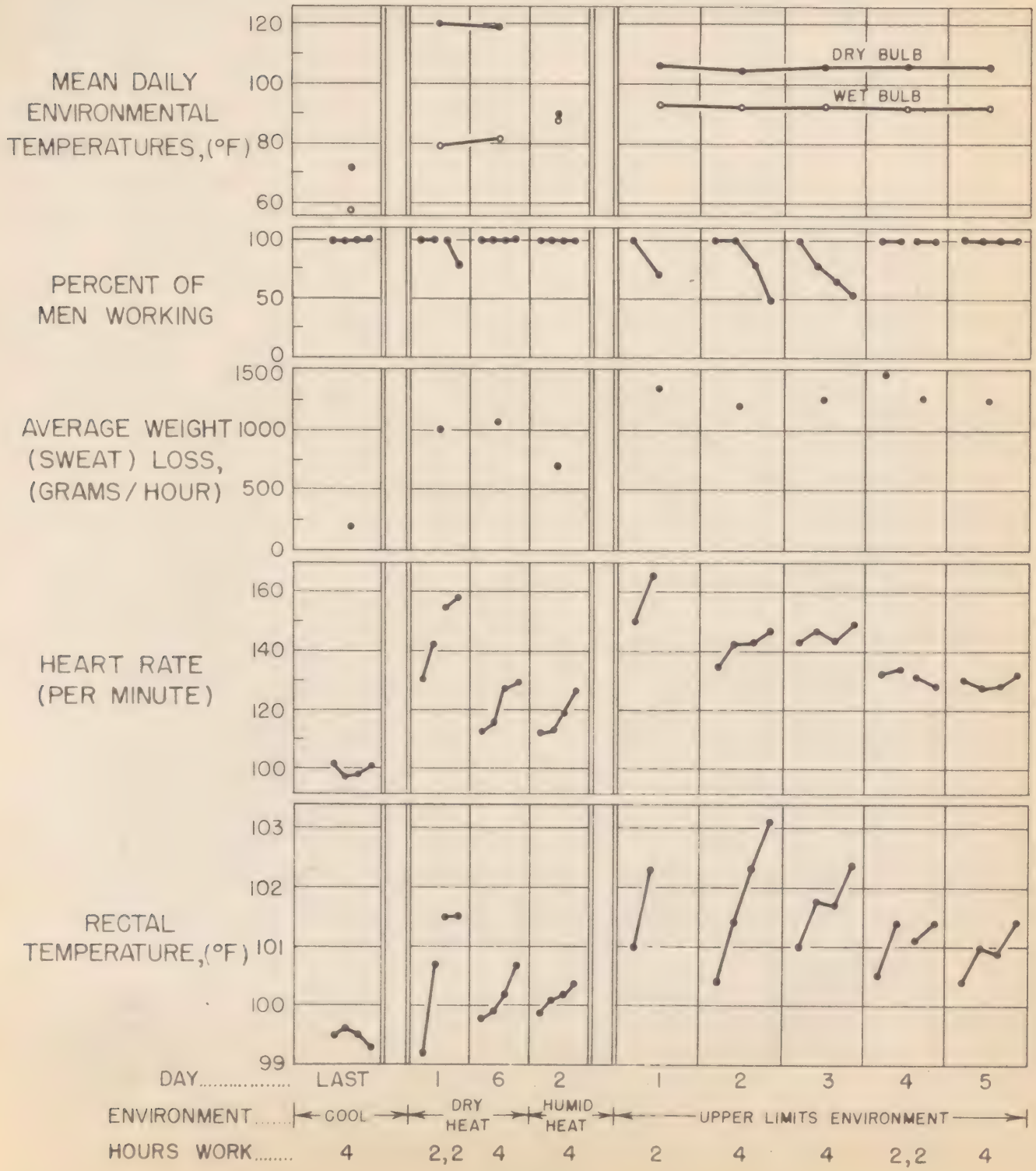


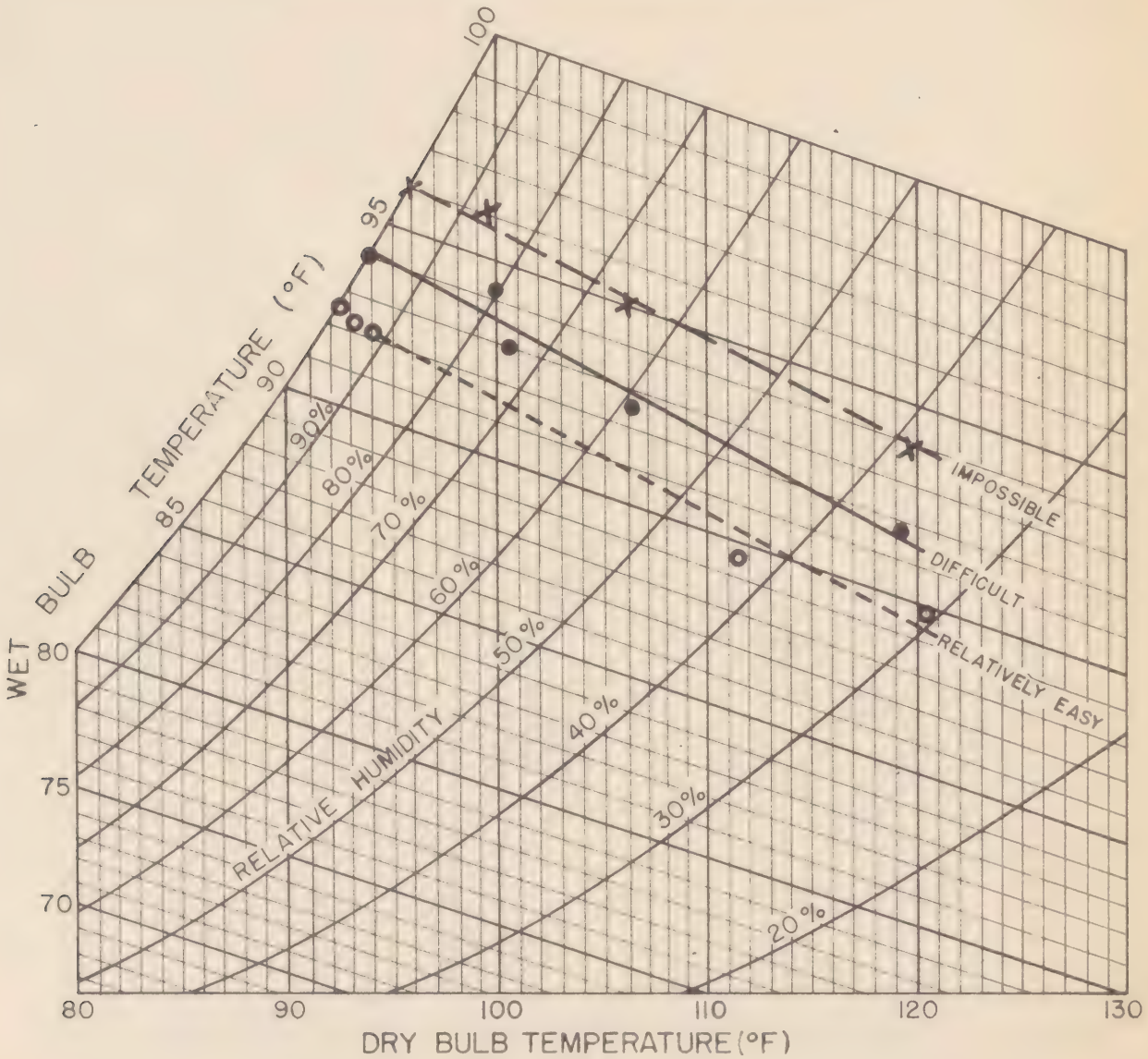
CHART 2

Incl. #2

CHART 3

ENVIRONMENTS IN WHICH PROLONGED MODERATELY HARD WORK (300 CAL/HR) WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE FOR ACCLIMATIZED SUBJECTS

PLOTTED ON PSYCHROMETRIC CHART



- KEY -

- ○ WORK RELATIVELY EASY
- ● WORK DIFFICULT
- X WORK IMPOSSIBLE

Incl. #3

CHART 3

RELATIONSHIP BETWEEN RELATIVE HUMIDITY AND DRY BULB TEMPERATURE IN DETERMINING THE ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT OR IMPOSSIBLE (ACCLIMATIZED SUBJECTS)

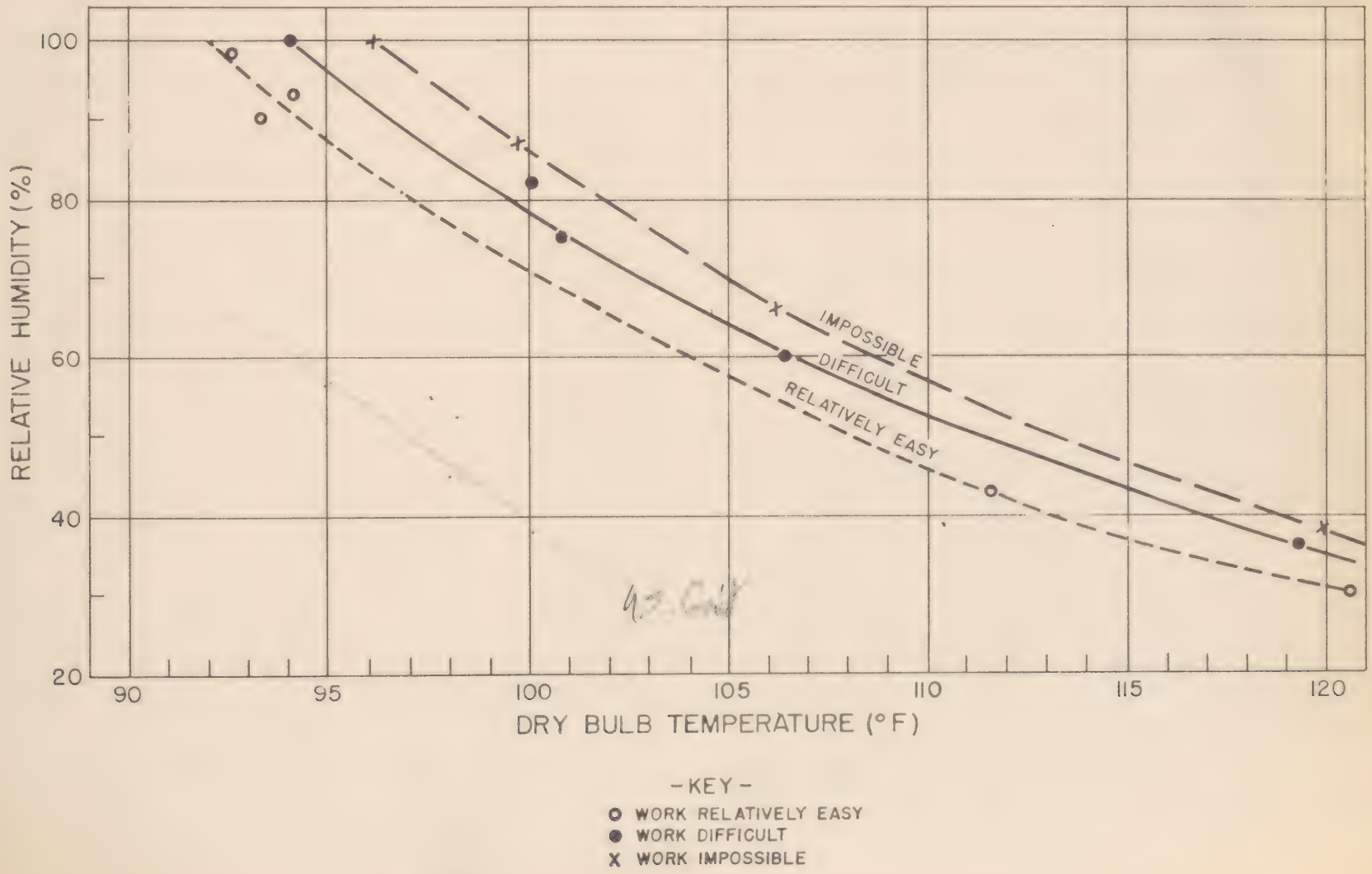


CHART 4

CHART 4

Incl. #3

THE ROLE OF THE WET BULB TEMPERATURE IN DETERMINING THE ABILITY OF ACCLIMATIZED MEN TO WORK IN A GIVEN ENVIRONMENT

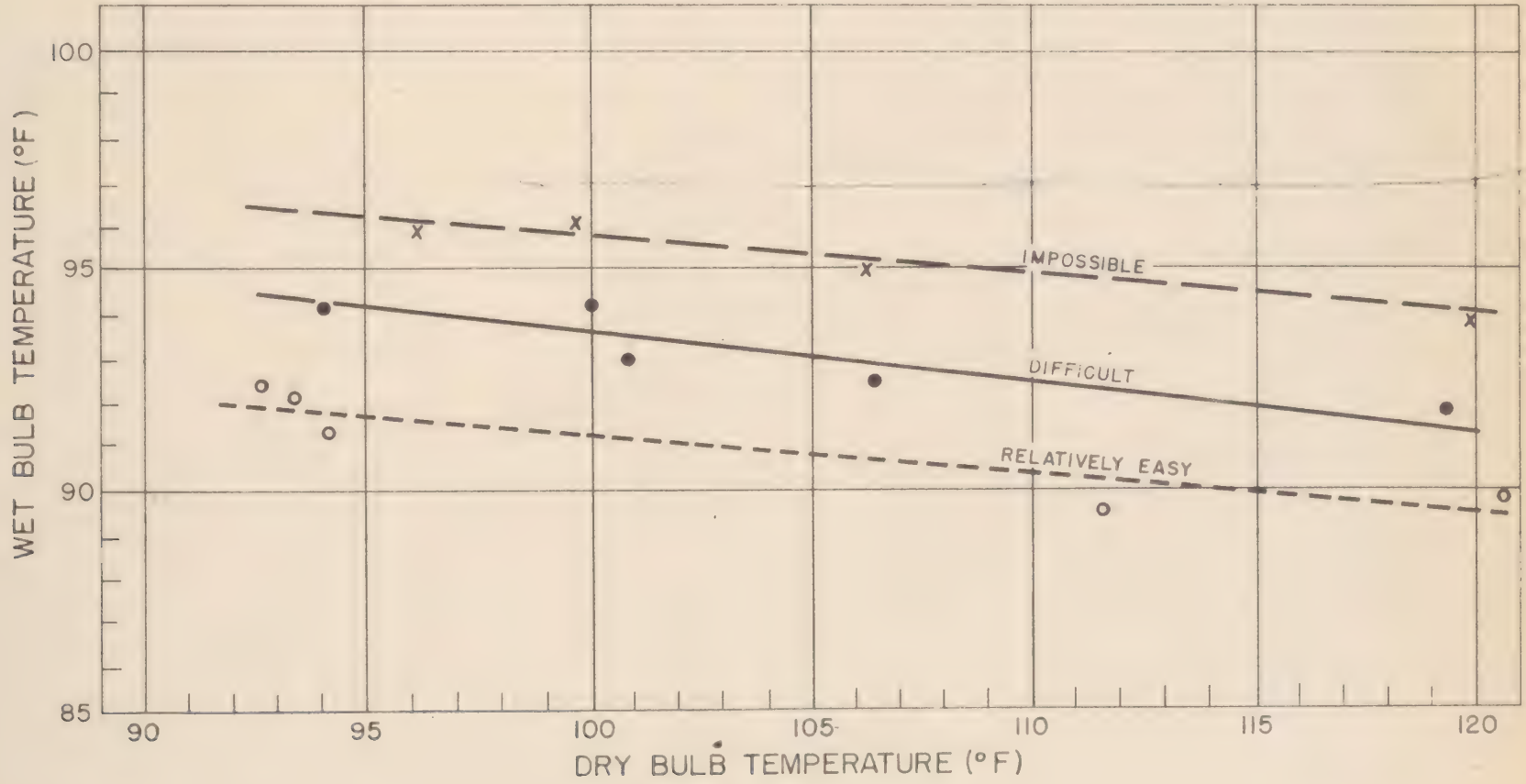


CHART 5

CHART 5

Incl. #3

THE EFFECTIVE TEMPERATURE AS AN INDEX OF THE TOLERABILITY FOR WORK IN HOT ENVIRONMENTS

(ACCLIMATIZED SUBJECTS)

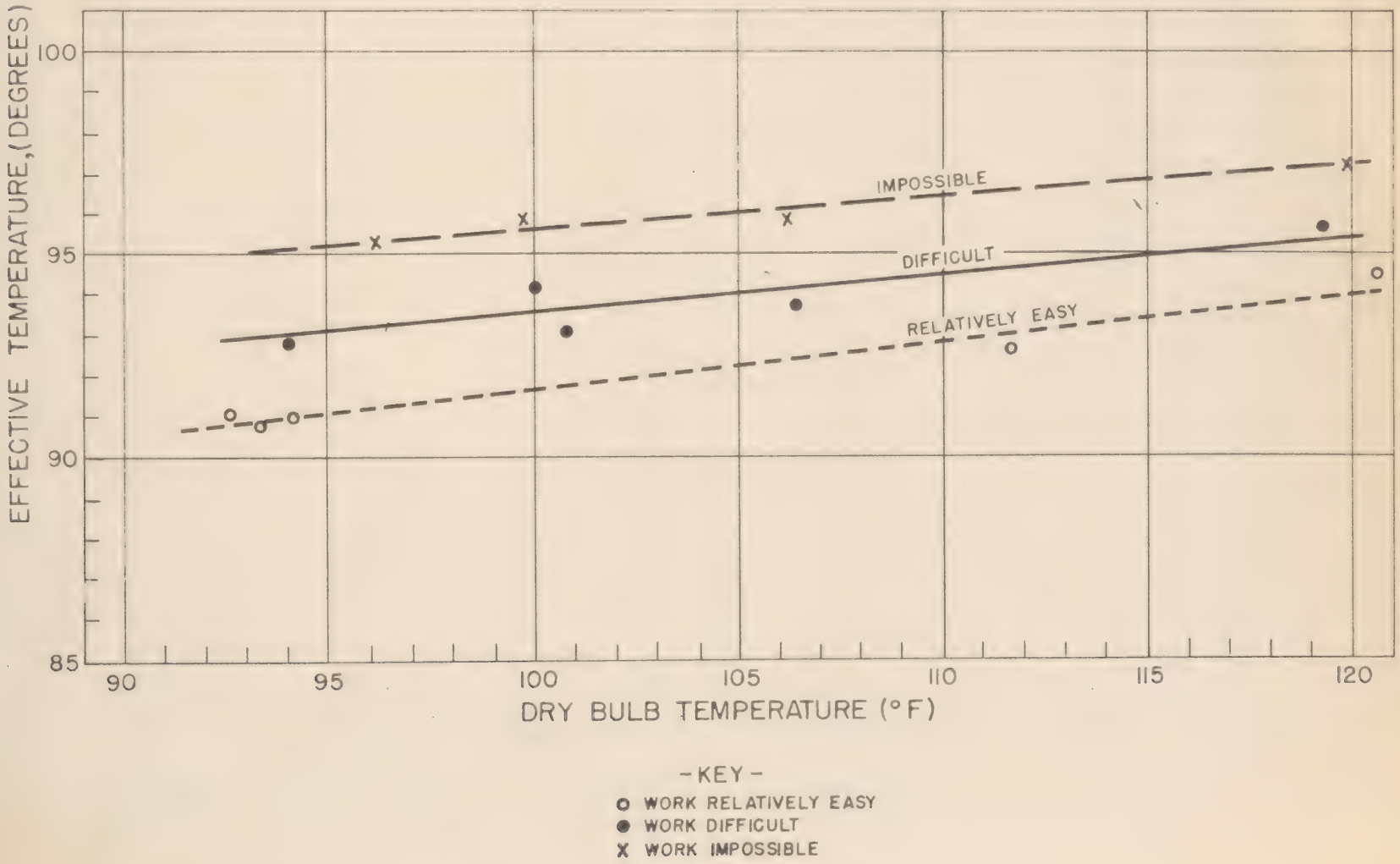


CHART 6

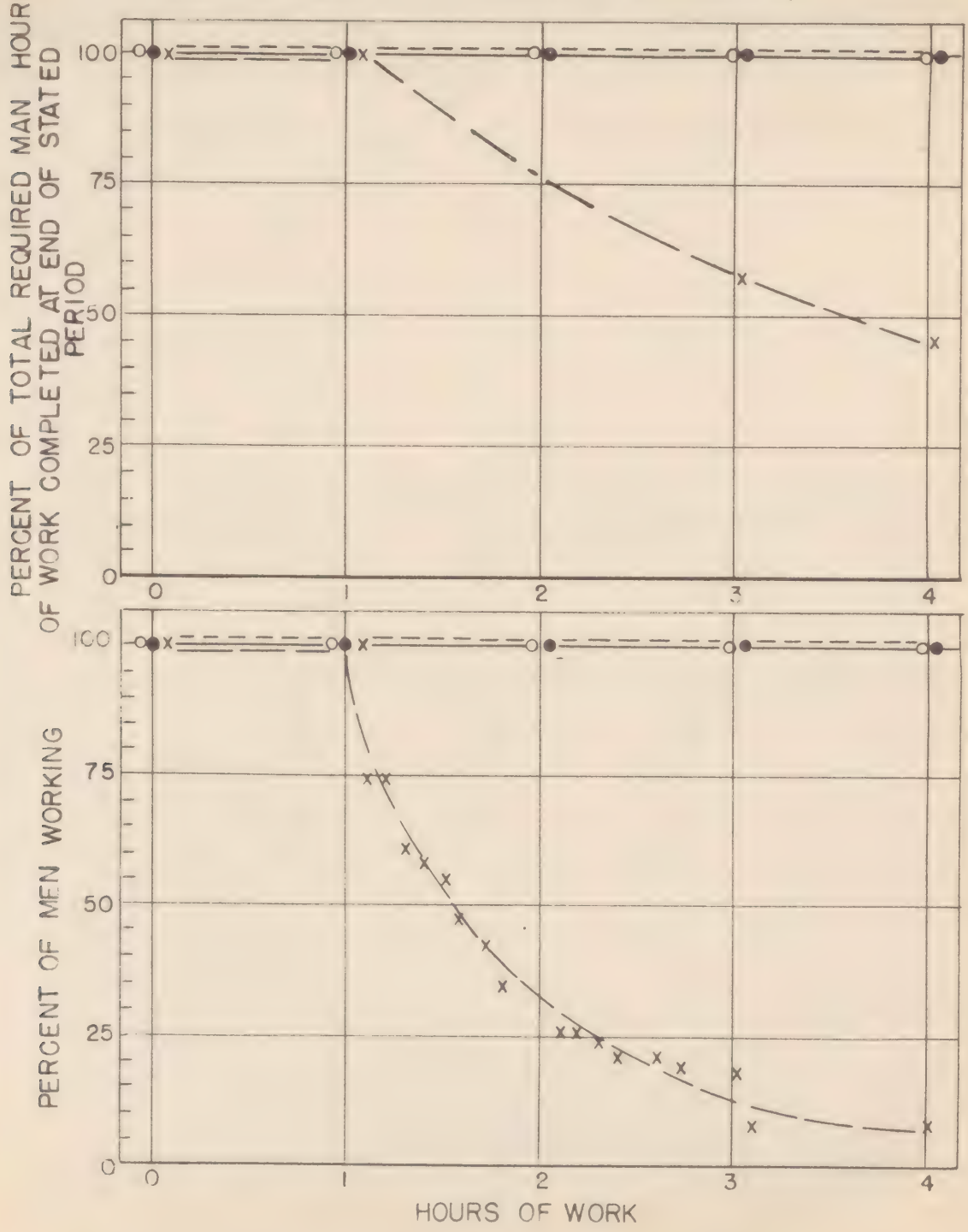
CHART 6

Incl. #3

CHART 7

AVERAGED WORK PERFORMANCE OF ACCLIMATIZED MEN IN HOT ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE

(ENVIRONMENTS AS INDICATED - IN CHART 3)



- KEY -

O WORK RELATIVELY EASY

● WORK DIFFICULT

X WORK IMPOSSIBLE

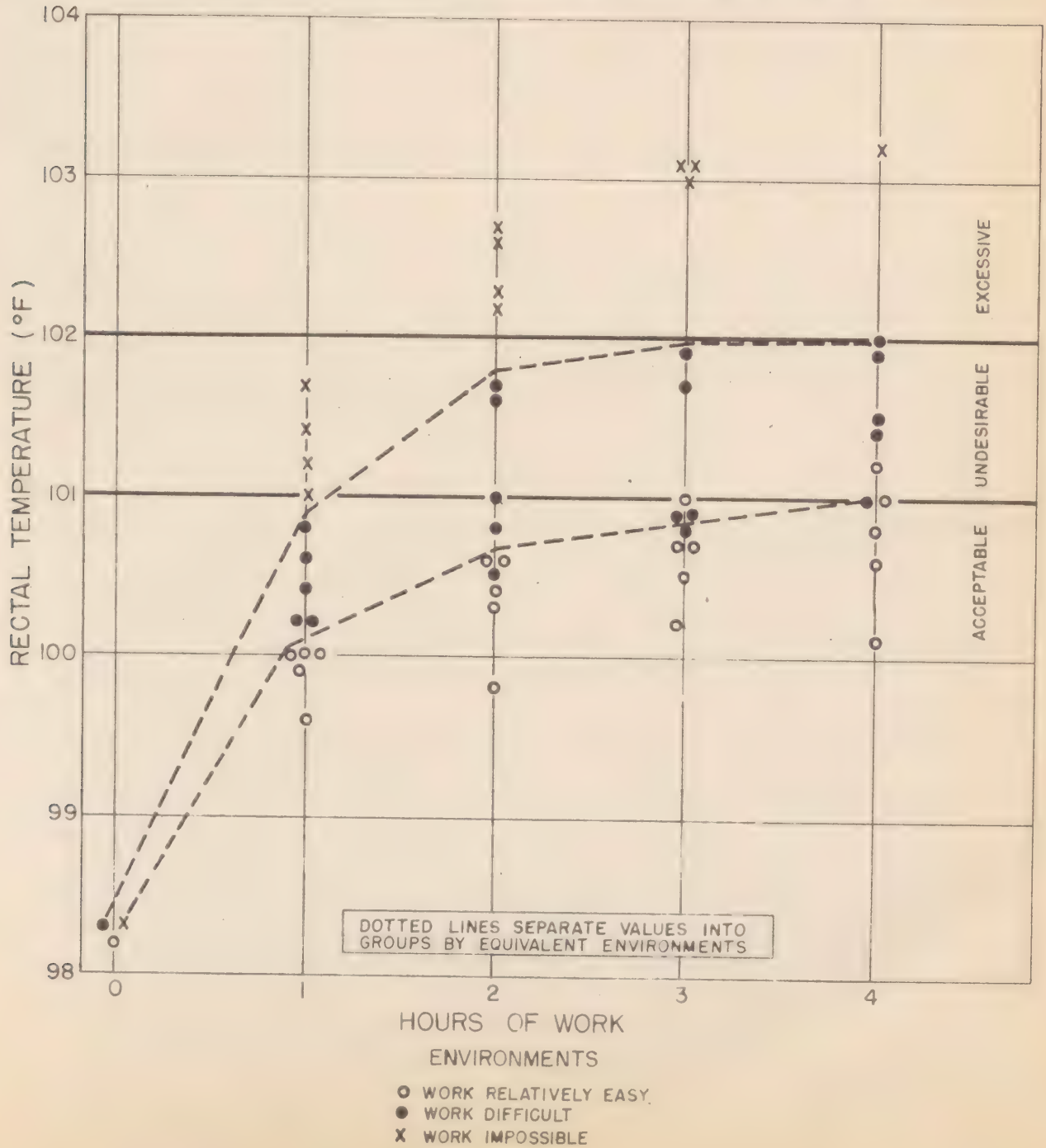
Incl. #3

CHART 7

CHART 8

RECTAL TEMPERATURES OF ACCLIMATIZED MEN WORKING IN HOT ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE

(ENVIRONMENTS ARE THOSE INDICATED IN CHART 3.)



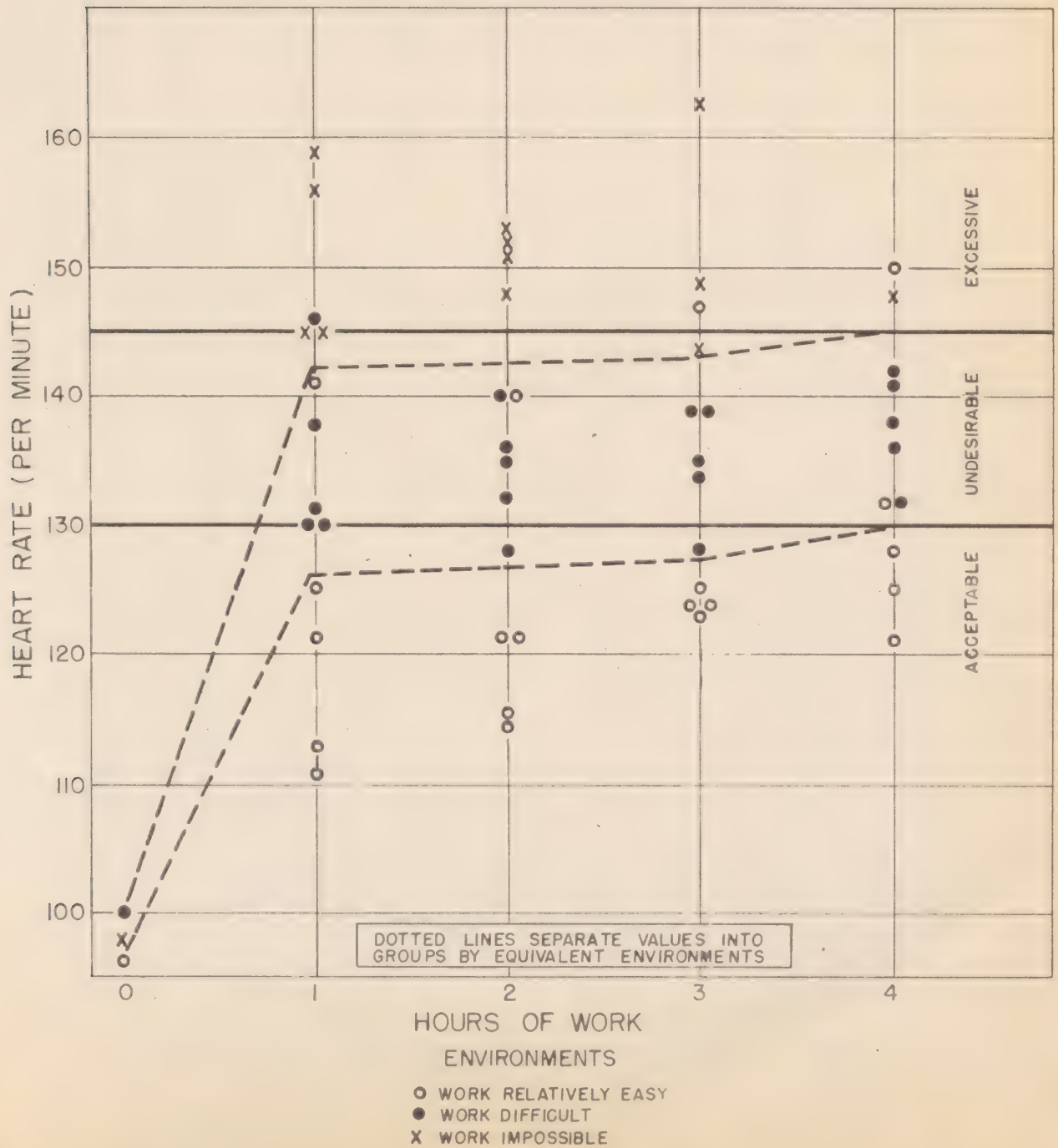
Incl. #3

CHART 8

CHART 9

HEART RATES OF ACCLIMATIZED MEN WORKING IN HOT ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE

(ENVIRONMENTS ARE THOSE INDICATED IN CHART 3)



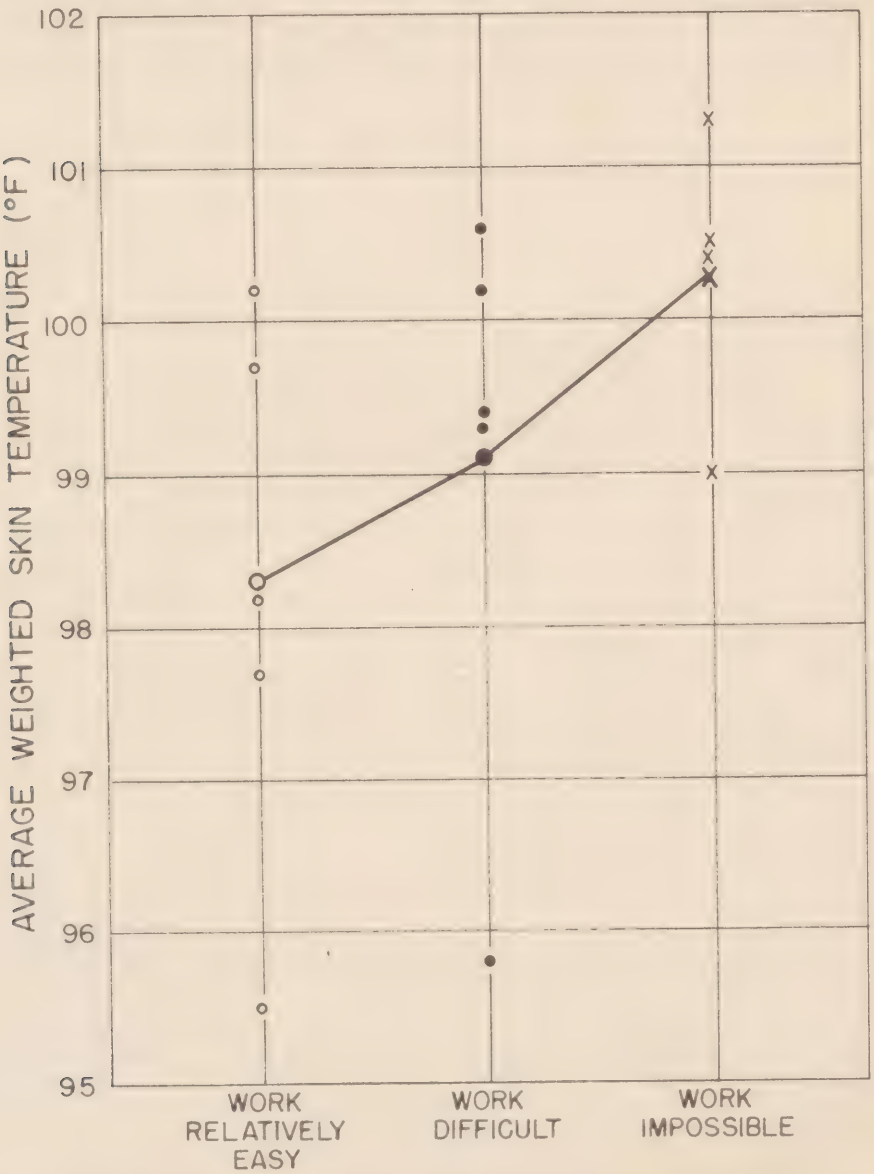
Incl. #3

CHART 9

CHART 10

AVERAGE WEIGHTED SKIN TEMPERATURES OF ACCLIMATIZED MEN ON COMPLETION OF WORK IN HOT ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE

(ENVIRONMENTS ARE THOSE INDICATED IN CHART 3)



EACH SMALL SYMBOL = ONE ENVIRONMENT

EACH LARGE SYMBOL = AVERAGE FOR THE EQUIVALENT ENVIRONMENTS

CHART 10

Incl. #3

CHART 11

RELATIONSHIP BETWEEN THE FINAL AVERAGE (WEIGHTED) SKIN TEMPERATURE OF THE BODY AND THE DRY BULB TEMPERATURE OF THE ENVIRONMENT (ACCLIMATIZED SUBJECTS)

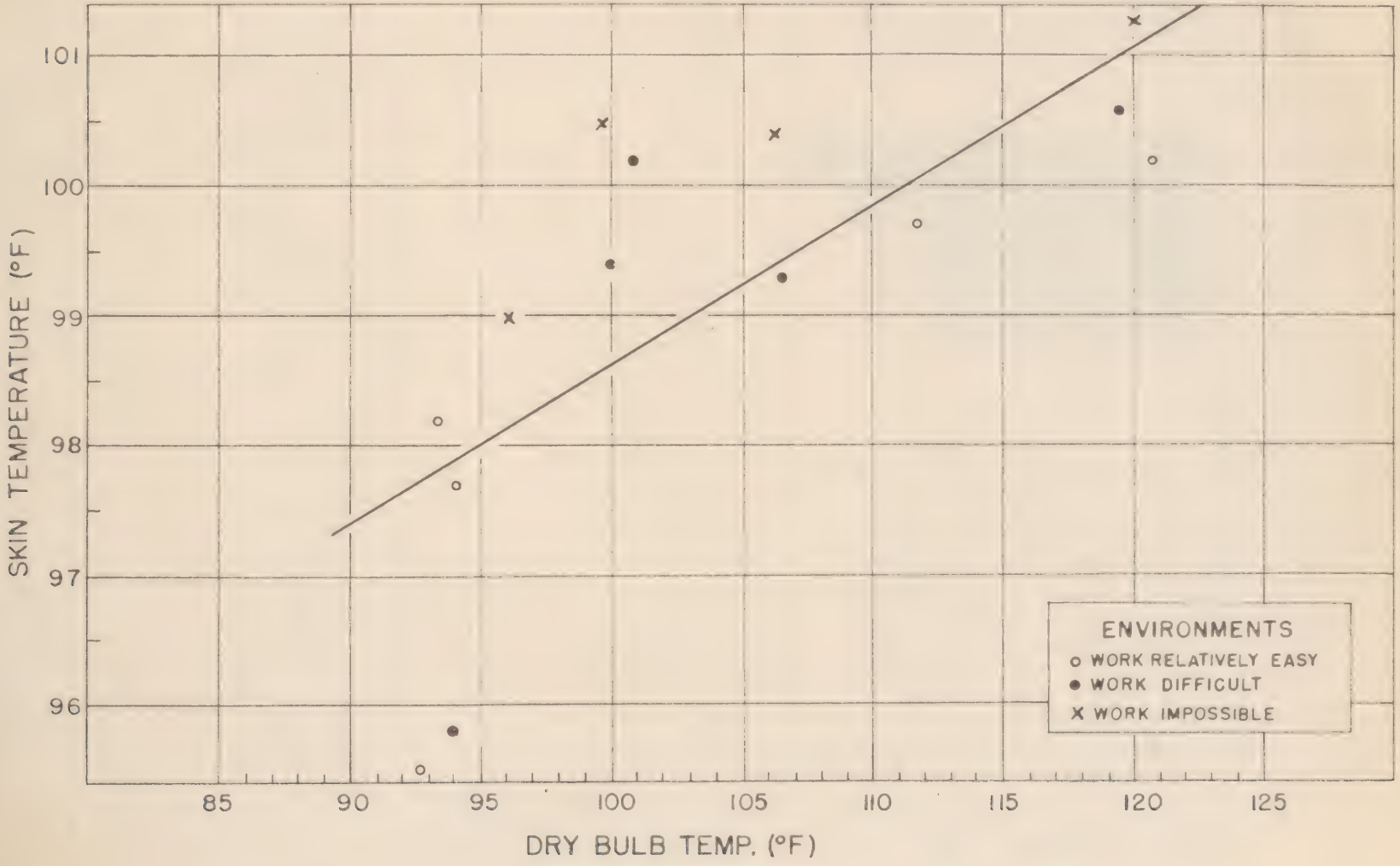


CHART 11

Incl. #3

CHART 12

WEIGHT (SWEAT) LOST PER HOUR BY ACCLIMATIZED MEN WORKING IN HOT ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE

(ENVIRONMENTS ARE THOSE INDICATED IN CHART 3)

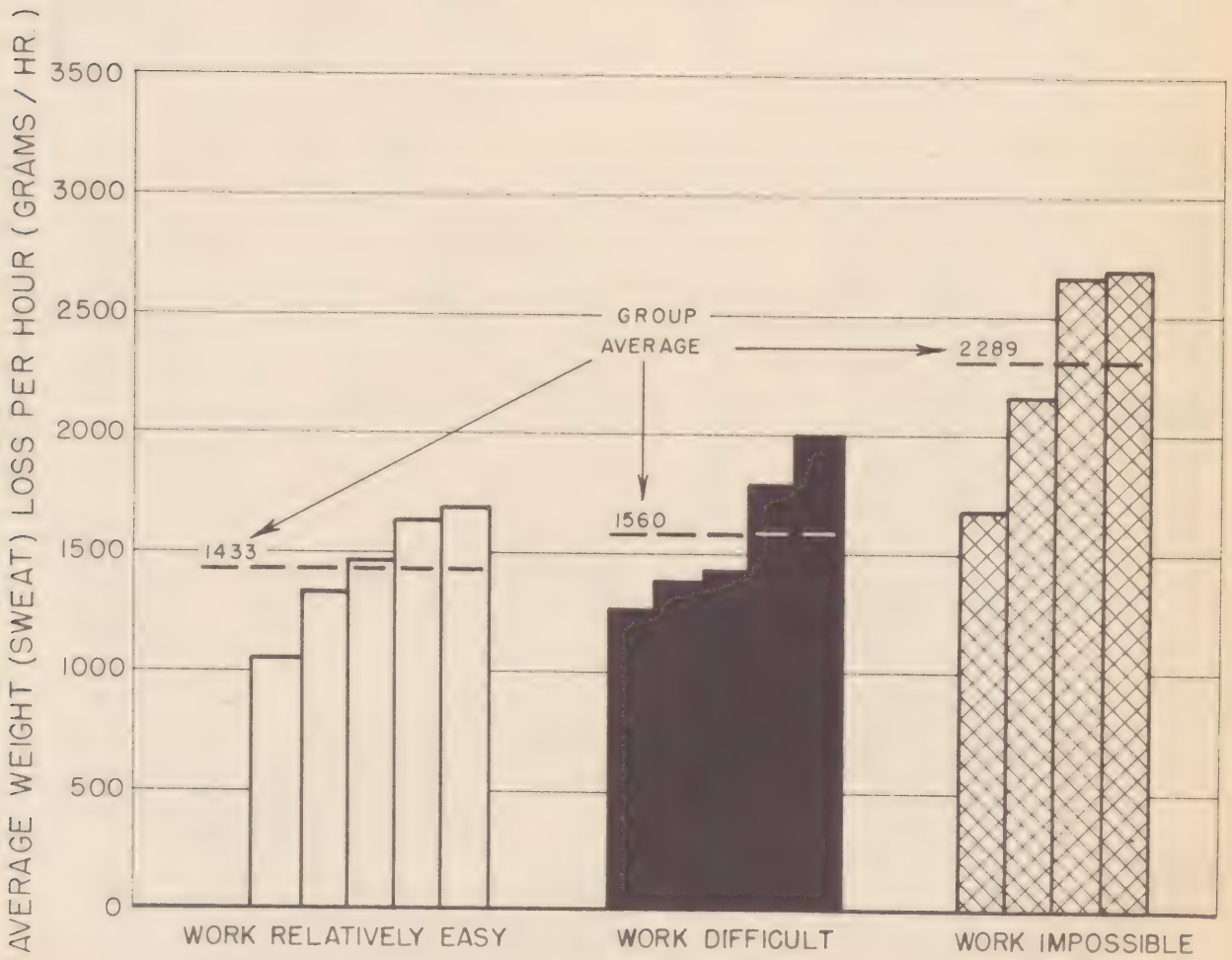


CHART 12

FLUID BALANCE PER HOUR OF ACCLIMATIZED MEN WORKING IN HOT ENVIRONMENTS IN WHICH WORK WAS RELATIVELY EASY, DIFFICULT, OR IMPOSSIBLE

(ENVIRONMENTS ARE THOSE INDICATED IN CHART 3)

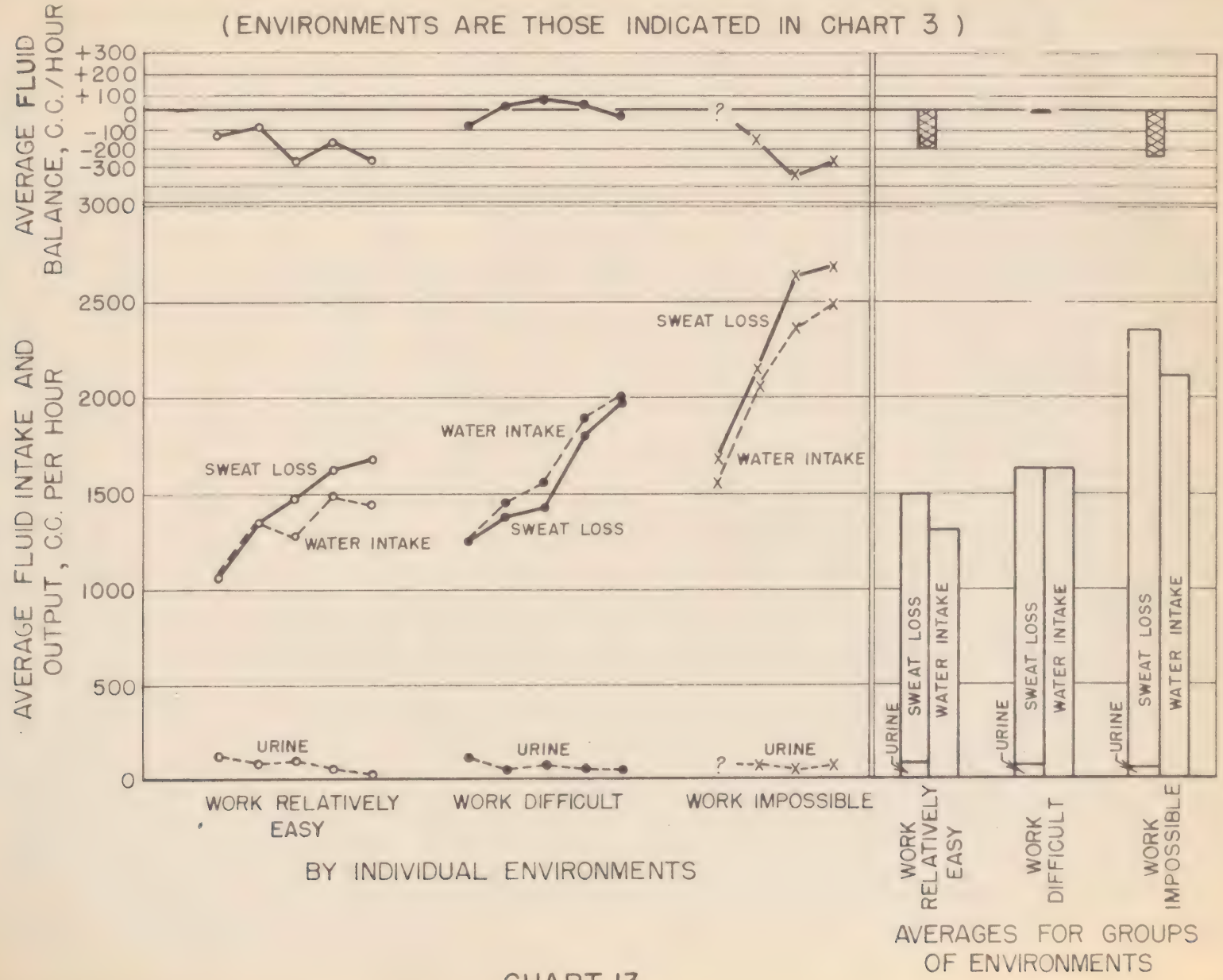


CHART 13

CHART 13

Incl. #3

CHART 14

PHYSIOLOGIC RESPONSES OF ACCLIMATIZED MEN WORKING IN COMPLETELY SATURATED HOT ENVIRONMENTS APPROACHING THE UPPER ENVIRONMENTAL LIMITS FOR WORK. NOTE THE PROGRESSIVELY INCREASED PHYSIOLOGIC CHANGES INDUCED BY SMALL ENVIRONMENTAL CHANGES.

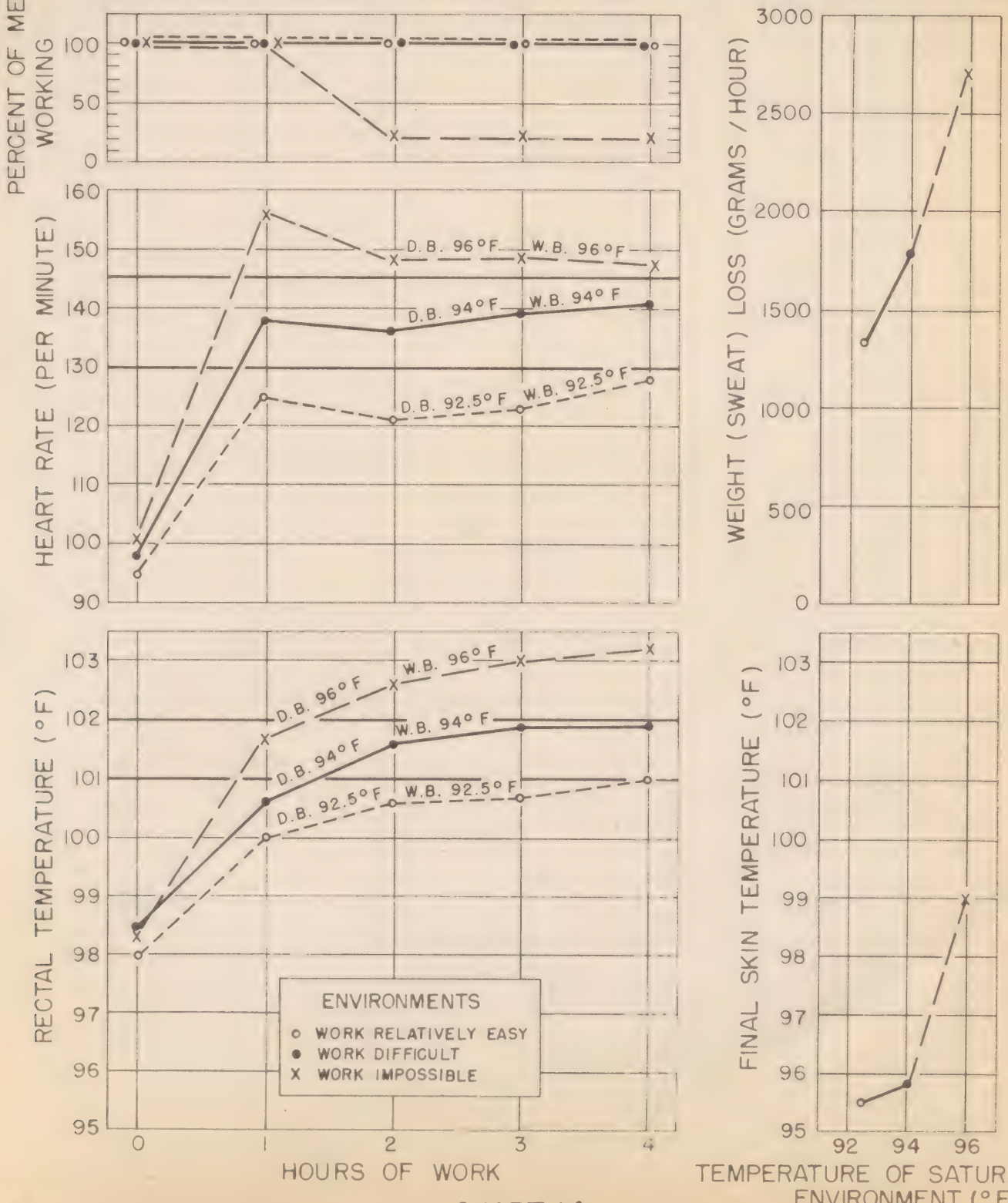


CHART 14

Incl. #3

CHART 15

PHYSIOLOGIC RESPONSES OF ACCLIMATIZED MEN WORKING IN HOT ENVIRONMENTS HAVING THE SAME DRY BULB TEMPERATURE BUT SLIGHTLY DIFFERENT WET BULB TEMPERATURES. PROGRESSIVE INCREASE IN PHYSIOLOGIC DISTURBANCES INDUCED BY SMALL INCREASES IN WET BULB TEMPERATURE

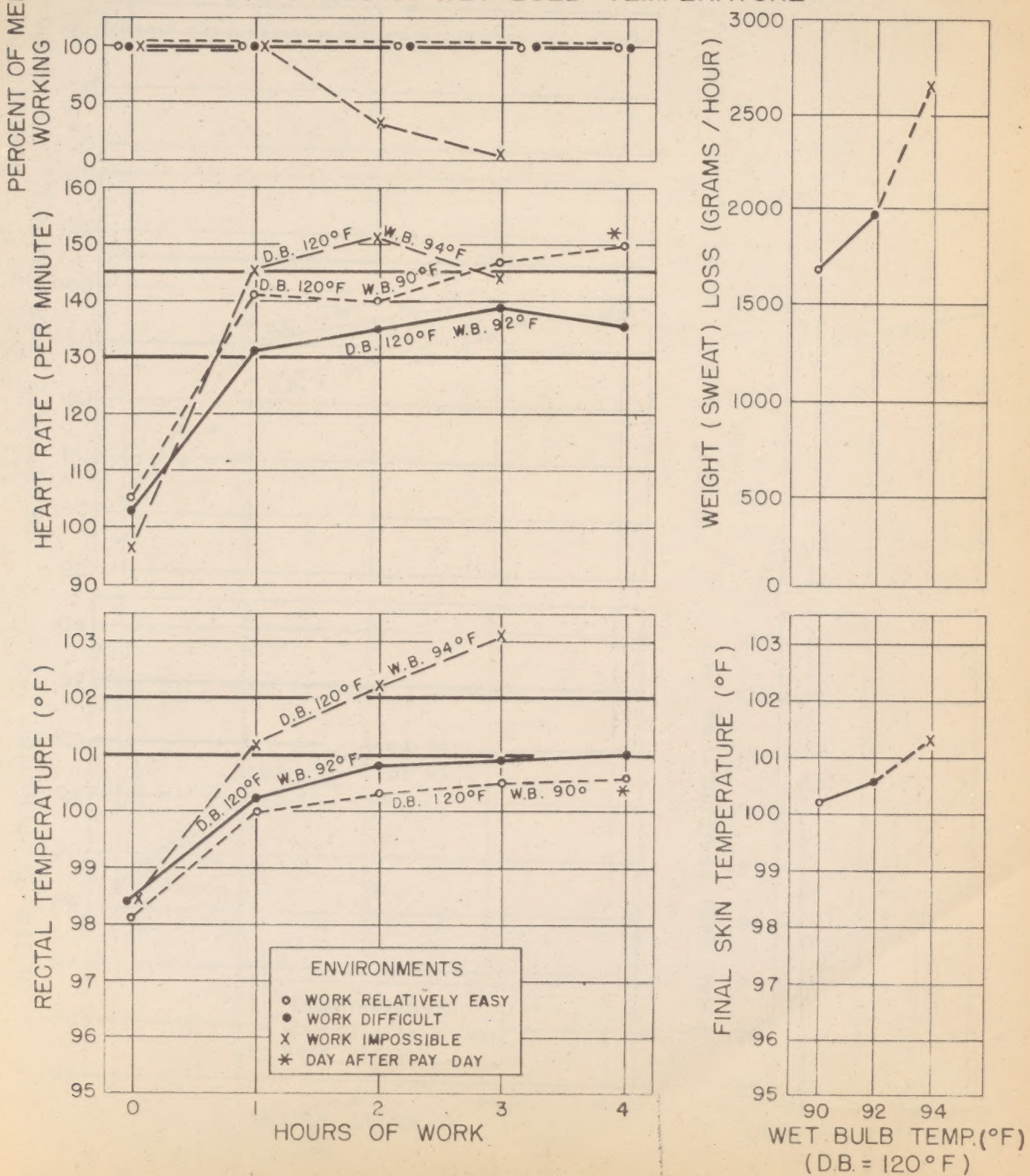


CHART 15

Incl. #3

CHART 16

PHYSIOLOGIC RESPONSES OF ACCLIMATIZED MEN WORKING IN HOT ENVIRONMENTS HAVING THE SAME WET BULB TEMPERATURE BUT WIDELY DIFFERENT DRY BULB TEMPERATURES

(NOTE SIMILARITY OF RESPONSES REGARDLESS OF LARGE DIFFERENCES IN DRY BULB TEMPERATURES)

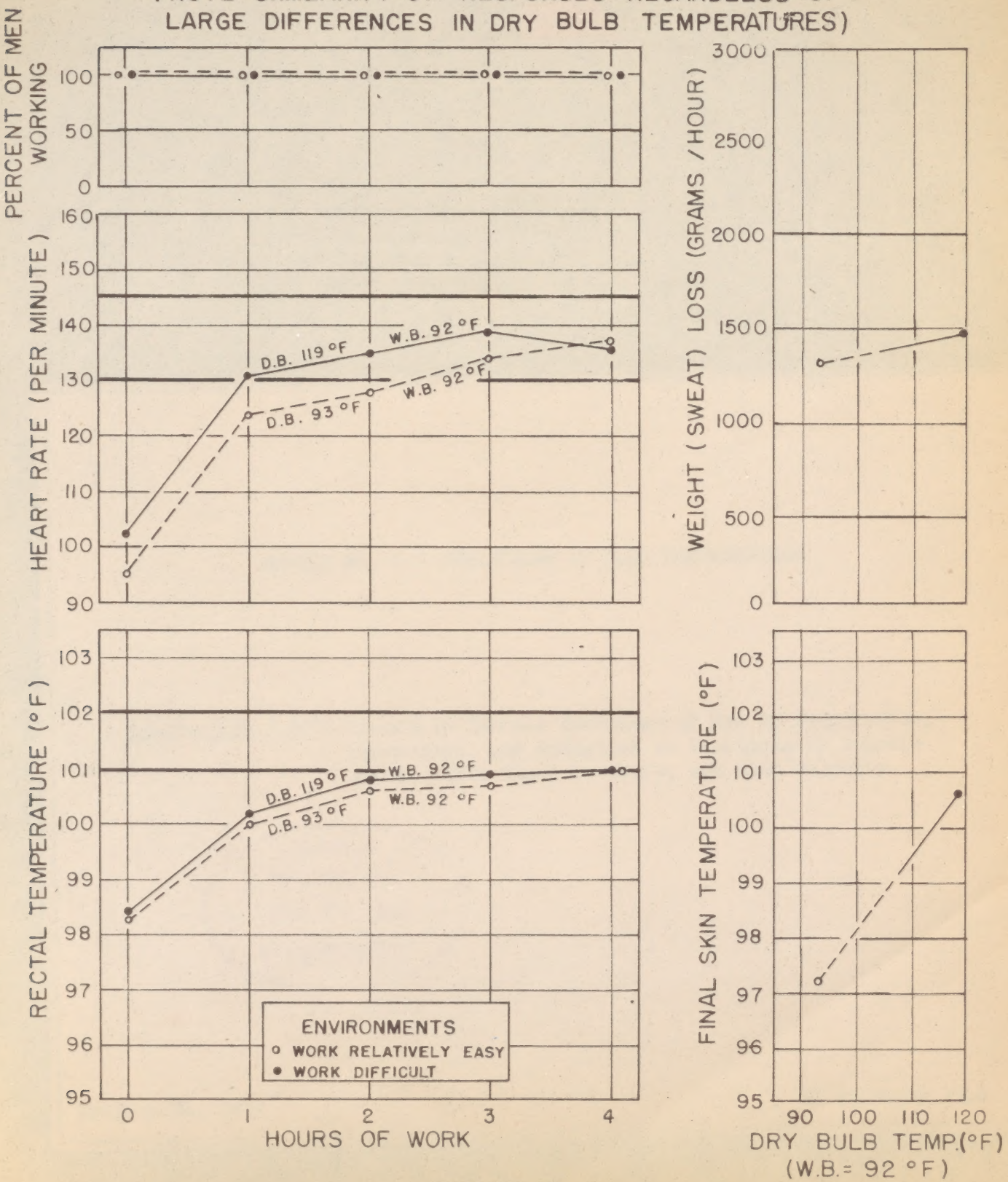


CHART 16

Incl. #3